Saskatchewan
Energy and Mines
Saskatchewan
Geological Survey

Report 195

Geology of the Athabasca Group (Helikian) in Northern Saskatchewan

Paul Ramaekers

1990

Printed under the authority of the
Minister of Energy and Mines

00-04312/

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Ramaekers, P. (1989): Geology of the Athabasca Group (Helikian) in Northern Saskatchewan; Saskatchewan Energy and Mines, Report 195, 49p.

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Manuscript submitted July 1988
Review and edit completed June 1989
Released January, 1990

Foreword

Dr. Ramaekers began his work on the Athabasca Basin in 1975 at a time when the major uranium deposits associated with the basin were beginning to be discovered. His work was closely associated with this major mineral exploration play, and contributed significantly to the development of the unconformity model for uranium deposits. In addition to the emphasis on uranium mineralization, this study and successor studies have also uncovered other areas of mineralization interest, including gold and rare earth elements.

Although some of these results have appeared in various other publications, they have never previously been systematically summarized as in this report. The work was carried out when Dr. Ramaekers was employed with the Sedimentary Geology section of the Saskatchewan Geological Survey. The original field work was partly supported with funds derived under the Canada-Saskatchewan Agreement for Mineral Exploration 1974-78 and its successor agreement 1978-80.

R. Macdonald
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Regina
June, 1989

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Preface

The following report, written in 1981, was based largely on outcrop studies made during the previous 5 years. As it stands the report is an internally consistent and systematic interpretation of that data. Its main limitations result from uneven exposure and less detailed coverage in the central and northwestern parts of the basin. Since then, industry has carried out much more work, including extensive drilling in search of uranium, largely around the basin margin and in the Carswell Structure. The additional work has led to a better understanding, especially of the coarser basal units, the Carswell area, and of the diagenesis and hydrothermal alteration of the sandstones.

The general stratigraphic sequence presented in this report still appears reasonable. Over limited areas the stratigraphy can be mapped in much greater detail. Maximum grain size of contained pebbles rather than percentage of conglomeratic beds is the most consistent mappable criterion, probably because it reflects stream power rather than sediment supply. Chemically, a very detailed and recognizable layering is discernable in the basin. Since the chemically distinctive strata are found in fluvial sandstones, they may be recognizable within the limits of a single deposystem, but it remains to be seen whether correlations can be made from one deposystem to another. These locally mappable sequences may be used to detect and map fault offsets between drill holes, even where faults are not actually intersected. Hence detailed stratigraphic analyses may be very important to exploration, especially in the deeper parts of the basin.

Lack of outcrop in the area around the Carswell Structure appears to have camouflaged a greater degree of disruption and vertical displacement than is evident in the eastern part of the basin. Drilling has revealed that the influence of the Carswell event extends well away from the prominent rim of the Carswell Structure. The structural disturbance has juxtoposed coarser sandstones (Tuma Lake Formation) intersected in core just below the Douglas Formation to outcrops of similar rock (Locker Lake Formation) across a relatively minor covered interval outside of the structure. At the time the report was written, outcrops of this coarser material were separated from the nearest known exposures of the generally coarse grained Locker Lake Formation by a much greater distance of poorly exposed units of the finer grained overlying Otherside Formation. The possibility that the coarser units belonged to the Locker Lake Formation was considered at the time but rejected because available exposures did not and still do not give any indication of the tectonic disruption that drilling revealed. Thus, the Tuma Lake Formation was erected to distinguish these coarser pebbly units below the Douglas and above the Otherside Formation.

John Wilson, of the Alberta Research Council, who mapped the Alberta part of the basin, found that the Locker Lake Formation is more abundantly exposed than suggested by available outcrop on the Saskatchewan side of the border. Subsequent drilling a few miles north of the Carswell Structure revealed that the Wolverine Point Formation is present below the till. Thus, Wilson's suggestion that the pebbly rock north of the Carswell Structure is part of the Locker Lake Formation is reasonable and probably correct. This would restrict the distribution of the Tuma Lake Formation to the pebbly material seen in the few drill holes that go through the Douglas Formation, and in one outcrop on the southern margin of the Carswell rim; rather scanty evidence to warrant the erection of a new formational name.

Most of the discussion of sedimentary environments in the report remains valid. The main change is in the interpretation of the clay-rich, basal units exhibiting low angle cross-bedding, poorly developed, partially eroded ripples, and rare thinly bedded (10 to 15 cm) sections showing herringbone cross-beds. These units are pebbly to cobbly near the basal unconformity and form the bulk of the Fair Point Formation and Manitou Falls (a) sequence. Because of their friability they form few outcrops. Sedimentary structures were originally interpreted as largely hummocky cross-bedding, which was used to infer a marine origin for these units. Subsequently, herringbone cross-beds have also been described from fluvial sands of these formations. Having logged many kilometres of core that intersects these units, it appears to me that the units are more likely to represent upper flow regime fluvial deposition rather than hummocky cross-bedding. This simplifies the paleoenvironment reconstruction considerably.

The boundary between nonmarine and marine units marking the first marine transgression probably lies somewhat below the Wolverine Point Formation. Marine deposition continued into the Locker Lake Formation when nonmarine conditions returned. The upper part of the Otherside Formation in some drill holes shows sedimentary structures similar to those in the Douglas Formation, which may indicate a return to marine conditions at this level. The boundaries are probably much more complex than the reconnaissance study suggests, but definitive proof must await more detailed mapping and sedimentological studies.

The continuing study of the diagenesis and hydrothermal alteration of the sandstones has emphasized the intense alteration that the interstitial clays have undergone, especially near the base of the Athabasca Group. Virtually none of the clays or iron oxides and hyroxides present now represent the primary depositional material. At least four generations of illite can be distinguished by careful, systematic examination of thin sections of the more altered areas near mineralization. Many of the other interstitial minerals also show similar complex histories.

P. Ramaekers

Calgary
September, 1989

Introduction

This study of the Athabasca Basin grew out of the renewed interest in uranium deposits found along the edge of the Athabasca sandstones. Begun in 1975 as a five year study to map the basin's edge more precisely, it was extended in 1978 to include the interior of the basin. Drill core collection was initiated in 1976 and core studies increased our understanding of the subsurface geology.

Results of this study include a better understanding of the stratigraphy and depositional environments of the Athabasca sandstones specifically and the thick pre-Devonian orthoquartzites generally, and the discovery of phosphorites and tuffs. This study shows the importance of diagenesis in altering the petrographic character of the sandstones, and provides a better understanding of the relationships that may exist between the unconformity-type uranium deposits and the thick orthoquartzite sequences at whose base they form exclusively. It also illustrates some differences between modern and Proterozoic marine shelf sedimentation and provides an example of an unmetamorphosed Proterozoic sandy shallow shelf sequence. This will help in the interpretation of the depositional environments of older metamorphosed strata and perhaps demonstrate the need for caution in applying coastal models based on post-Devonian sequences to older units.

The stratigraphic nomenclature introduced to facilitate discussion of the complex deposits of the Athabasca Basin are summarized in Table 1. The major units define four transgressive marine sequences with sediment input from the east and south and a major fluvial wedge entering the basin from the east.

Previous Stratigraphic Work on the Athabasca Group

The definition of the 'Athabasca sandstone', 'Athabasca formation' or 'Athabasca series' has changed frequently since McConnell (1893) first applied the name 'Athabasca sandstone' to outcrops of the Locker Lake and the sandy part of the Wolverine Point Formations on the southeast shore of Lake Athabasca. This instability was due to the reconnaissance nature of the early studies or because observations were very local, centered around mining camps. A brief review of the early literature is given in Fahrig (1961).

Two approaches to the stratigraphy of the unmetamorphosed clastics of the Athabasca region are evident in the literature. McConnell (1893), Sproule (1938, 1941), Sproule and Downie (1941), and Sproule, Ells and Downie (1941) used the term 'Athabasca sandstone' exclusively for the flat-lying, little deformed, quartz sandstones, which underlie and occur south of Lake Athabasca and the Fond-du-Lac River. On the other hand, Tyrrell and Dowling (1896), Alcock (1920, 1936a, 1936b), Furnival (1941), Christie (1952, 1953), Fraser (1954), Hale (1954a, 1954b, 1955), and Blake (1956) expanded the concept to include the folded redbed deposits north of Lake Athabasca and Hale even included the weakly metamorphosed clastics of the Thluicho Lake Group also found there (Figure 1). Blake (1956) noted the distinctiveness of the Athabasca Group sediments and the Martin Formation, but retained the term 'Athabasca series' for both. He also discovered carbonates in the Athabasca Basin and named them the Trout Lake limestone after Trout Lake (now Carswell Lake).

Gussow (1957, 1959), reconsidering Blake's data, formalized Blake's observations by placing the folded redbeds in the 'Martin Lake series', including the Thluicho Lake Group. He regarded Blake's carbonates, now the Trout Lake member, as the upper unit of the Athabasca Formation, the lower unit of which was the flat-lying quartz sandstones. Gravenor (1959) was the first to differentiate the sandy units within the Athabasca Group but Fahrig (1961) retained the term 'Athabasca formation' for all the flat-lying quartz sandstones of the region. Fahrig clearly distinguished the Athabasca Formation from the folded redbeds north of Lake Athabasca, which he termed the Martin Formation, and the clastics of greenschist grade (Thluicho Lake Group) which he included in the Tazin Group, although he did recognize the presence of unconformities within this sequence. Fahrig raised the 'Trout Lake member' to formation status, calling it the 'Carswell Formation', to accommodate the change in the name of the lake. Donaldson (1968) pointed out the presence of beds unlike the typical Martin or Tazin Group sediments at Slate Island along the north shore of Lake Athabasca. Scott (1978), mapping to the east and north of Slate Island, named the greenschist facies clastics of this type in the Thluicho Lake Group, but he did not name the component formations that he described informally. Amok (1974) erected the 'Douglas Formation' for the largely black and grey mudstones, siltstones and sandstones lying between the Athabasca and Carswell Formations.

Most authors after 1961 followed Fahrig's nomenclature and boundaries, although various small areas of Thluicho Lake Group and redbed conglomerates adjacent to and underlying the Athabasca Group along the north shore of Lake Athabasca are still not adequately defined and are regarded as part of the Athabasca Formation. A seismic survey by Hobson and MacAulay (1969) established the Athabasca Basin to be about 1500 m deep and suggested that significant amounts of faulting had occurred. Currie (1969) suggested a two-fold division of the Athabasca Formation within the Carswell Structure, based on texture and degree of hematization. Facies changes at the base of the Athabasca Group, not mappable on a regional scale, are being recorded (Mellinger, 1980; this report). Most of the information collected on the Athabasca Group since Fahrig's (1961) study has been incidental to studies on the area, and not directly concerned with the sandstones. It has served only to provide more precise boundaries.

Table 1 - Formations and sediment source areas of the Athabasca Group arranged to show depositional environment and geographic distribution.

	Sedimentary Environment	*Jackfish Basin*	*Mirror Basin*	*Cree Basin*	*Source Area*
Points Lake Subgroup	marine	Carswell Fm.			
	marine	Douglas Fm.			NE?
	marine	Tuma Lake Fm.			
			unconformity		
	marine	Otherside Fm.	Otherside Fm.		S,E,NE
	marine	Locker Lake Fm.	Locker Lake Fm.		
			unconformity		
	marine	Wolverine Point B	Wolverine Point B	Wolverine Point A	S
	marine	Wolverine Point A	Wolverine Point A		S
	marine		Lazenby Lake Fm.		
			unconformity		
William River Subgroup	non-marine	Manitou Falls D	Manitou Falls D	Manitou Falls D	E,NE
	non-marine	Manitou Falls C	Manitou Falls C	Manitou Falls C	E,NE,S?
	non-marine			Manitou Falls B	E,NE,S (minor)
			unconformity		
	marine	Fair Point Fm.	Manitou Falls A (marine in part)		local;S,E?
			major unconformity		
			Metamorphosed basement		

Recent mapping studies aimed specifically at the Athabasca Group began with the Saskatchewan Geological Survey's Athabasca Program (Ramaekers, 1975, 1976, 1977, 1978a, 1978b, 1979a, 1979b, 1980a). Ramaekers and Dunn (1977) and discussed the relationship between the geology and lake sediment geochemistry of the eastern Athabasca Basin. The intrusives and tectonics of the Athabasca Basin were discussed by Ramaekers and Hartling (1979). Langford (1980) undertook an ongoing study of the various redbed basins north of Lake Athabasca and defined the Charlot Point Formation for conglomeratic redbeds at Charlot Point.

The suggestion that the uranium mineralization in the Athabasca Basin is directly related to the character and diagenetic history of the Athabasca sandstones (Hoeve and Sibbald, 1978; Hoeve, Sibbald, Ramaekers and Lewry, 1980; Ramaekers, 1979c, 1980a) and the discovery of widespread phosphates and tuffs within the Athabasca Basin (Ramaekers, 1980a) will no doubt spur further interest in these sediments and lead to a better understanding of the basin.

Data Base, Methods and Limitations of this Study

This report is based on the study of 1179 outcrops (Map 1) of the Athabasca Group, from which 10,023 paleocurrent measurements were obtained (Figure 2). Over 17 600 m of Athabasca core was logged from 45 boreholes. Many other cores and outcrops were examined in lesser detail. Outcrops were selected so as to provide an evenly spaced coverage of the Athabasca Basin. Time available precluded detailed sedimentological studies at this stage. Drill core data showed that the outcrops form a biased sample of the rock types present, in particular that the friable conglomerates and mudstones are poorly exposed due to glacial excavation. This means that the conglomeratic members of the Manitou Falls, Wolverine Point, Tuma Lake and Douglas Formations, as well as the silt and mudstones of the Otherside Formation are under represented in outcrops. Silicified zones within all formations are probably over represented. Core loss of friable units ranged from extensive in small diameter (45 mm, AQ and smaller), to minor in large diameter (45 mm, BQ and larger) core. Many boreholes were abandoned in friable units because of drilling problems, thus causing these units to be under represented even in cores. Friable, in places almost unconsolidated, zones are not uncommon near the base of the Athabasca Group and thus many holes were abandoned before reaching basement. Very few deep holes are available from the central part of the basin making the geological interpretations rather speculative. Lack of outcrop and drill cores of the Tuma Lake Formation makes conclusions about this unit tentative.

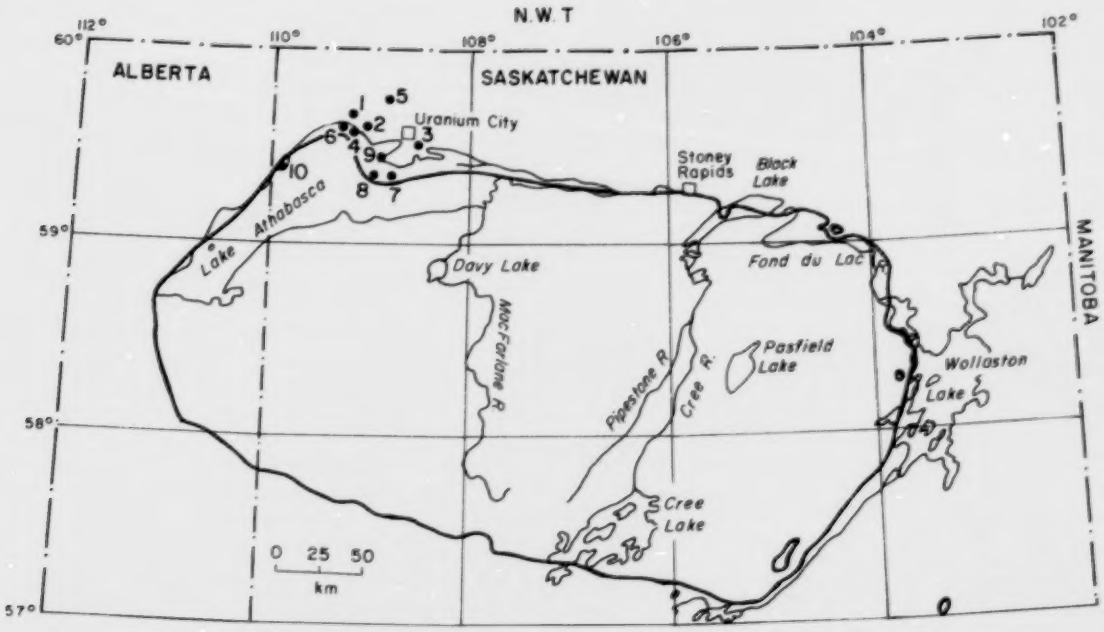

Figure 1 – Location of Hudsonian pre-Athabasca Group Sedimentary Basins and Intrusives in the Athabasca Region: 1) Thluicho Lake Group, 2) Ellis Bay Formation, 3-10) Redbed occurrences, 3) Martin Formation, 4) Charlot Point Formation, 5) Tazin Lake redbeds, 6) Slate Island, 7) Stewart Island, 8) Johnston Island, 9) Gruchy Island, and 10) Maurice Bay.

Athabasca Group outcrops are generally covered with lichen that, aside from making the outcrop difficult to find, is hard to remove, unlike the lichen and moss cover of many types of hardrock. Lichen cover is probably the main reason why so few outcrops of the Athabasca Group were found by previous studies. In some cases the lichen makes the outcrop unusable for sedimentological work. Outcrops of the Athabasca Group are usually flat and, if large enough, are useful for paleocurrent studies; however, very few expose enough vertical section to facilitate the construction of facies models.

Drill cores of the Athabasca Group are typically small in diameter (45 mm or less) and, as much of the rock is friable, sedimentary structures are often difficult to identify. The presence or absence of cross-bedding can generally be ascertained but more precise identification of the various types of cross-bedding is difficult. In the coarser grained units much of the core appears massive, although the few corresponding outcrops show abundant sedimentary structures. Thus, the interpretation of depositional environments from the sequence of sedimentary structures is difficult in both outcrop and core studies.

The apparent homogeneity of the thick Proterozoic sandstones resulted in their being regarded as a single formation. To elucidate their complex history and provide a useful stratigraphic division of the Athabasca Group, distinctions in texture were made, which although relatively subtle, proved mappable at a regional scale. However, the repetition of lithologically similar units at four levels in the sequence makes their identification difficult in tectonically disturbed areas such as the Carswell Structure. Similarly, it may not be possible to identify isolated glacial erratics beyond the subgroup level.

The maps accompanying this report also include the area underlain by the Athabasca Group in Alberta. Published information and limited data obtained during brief visits to that region are plotted on the maps. An interpretation, based largely on an extrapolation of data from the Saskatchewan side, is offered.

The Athabasca Basin was mapped using boats, fixed wing, piston helicopter and turbine powered helicopter support. A Hughes 500 C or D helicopter on high skids eventually proved to be the most suitable and cost-effective method in terms of the number of outcrops studied. Thus in areas of sparse outcrop typical of the Athabasca Basin more detailed coverage was obtainable.

At each outcrop, mineralogy, texture, cements, diagenetic effects (especially on quartz and iron oxides) and structural geology were studied. The types of sedimentary structures and their relative frequencies were noted. An attempt was made to record at least 15 paleocurrent measurements using trough axes, in ad-

dition to measurements on other types of directional structures. A handspecimen representative of the outcrop was taken, as well as specimens of any unusual lithology or structure. Glacial and periglacial effects such as striae and eolian grooving were noted. Till samples were obtained along the edge of the basin.

After the 1978 field season, the basic stratigraphy and structure of the Athabasca Basin became evident (Ramaekers, 1978b). The field work done in the summers of 1979 and 1980 served to check problem areas and to find more outcrop in areas of poor exposure. This report is concerned mainly with the field relationships and observations at the macroscopic level.

Within the Athabasca Group very few formational contacts are exposed. Geological boundaries were drawn using outcrop data and core data projected to the surface. Using this information, boundaries that were defined within a few miles are shown on Map 2 as 'approximate'. Unless noted otherwise, all drill cores mentioned in this report are open to examination by the public at the Saskatchewan Department of Energy and Mines Geological Subsurface Laboratory, 201 Dewdney Avenue East, Regina.

Topographic lineaments, the distribution of glacial features, drainage patterns, and geomagnetic data (Agarwal, 1962; 1965a; 1965b) were used in areas where the number of outcrops and drill holes was inadequate. These boundaries are shown as 'inferred'. If such indirect evidence of geological boundaries was not available or conclusive, linear interpolation between outcrops was used.

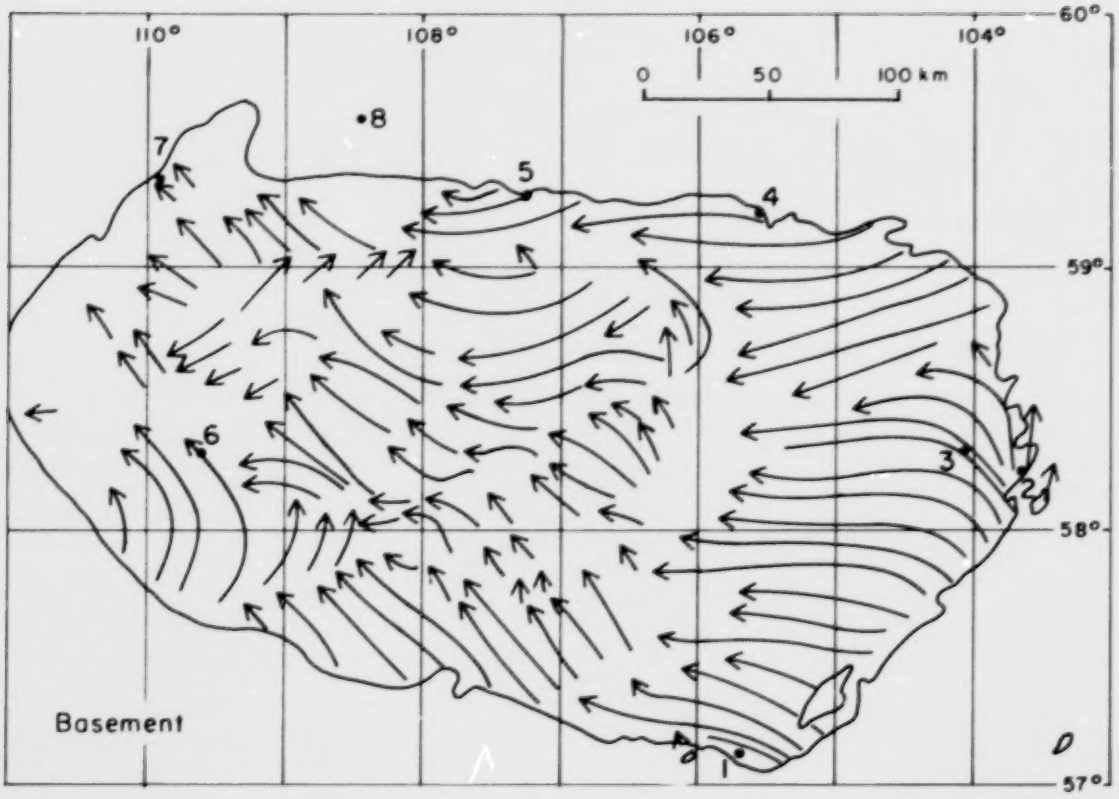

Figure 2 – Paleocurrent directions. Locations 1) Key Lake, 2) Rabbit Lake, 3) Midwest Lake, 4) Black Lake, 5) Fond-du-Lac, 6) Cluff Lake, 7) Maurice Bay, 8) Uranium City.

Stratigraphy

The sediments of the Athabasca Group locally cover older clastics at the edges of the basin, namely the Late Hudsonian unmetamorphosed redbeds - including those of the Martin Formation and the older greenschist grade sandstones, conglomerates and greywackes - of the Thluicho Lake Group. Relations between these basins are difficult to decipher because the preserved erosional remnants lack good mutual contacts and not enough radiometric dates are available. The following discussion of the Thluicho Lake and Martin sequences is based largely on work by Tremblay (1972) and Scott (1978) supplemented by that of the author.

Aphebian or Hudsonian Basins: the Thluicho Lake Group and Related Sediments

The Thluicho Lake Group (Scott, 1978) rests unconformably on the Archean (?) metasediments of the Tazin Group from which it is derived and is preserved in at least two complexly folded synclinal basins (Figure 1). Similar rock-types are known from boreholes along the northwest side of Lake Athabasca where they underlie the Athabasca Group (Harper, 1979). The group also occurs on Slate Island as the 'Martin or Tazin' in work by Donaldson (1968). In the type area the Thluicho Lake Group consists of a basal metaconglomerate up to 1000 m thick, conformably overlain by a meta-arkose and an argillite. In all three units chlorite, muscovite, biotite and albite are common. Graded bedding, cross-bedding, ripple marks and load structures are locally abundant. The unconformably overlying Ellis Bay Formation contains some reworked Thluicho Lake clasts, but consists largely of monomictic, massive, felsic breccia containing rounded fragments of aphanitic albite in a softer matrix. It may represent a volcanic rock subjected to brecciation and retrograde metamorphism (Scott, 1978). Detailed sedimentological work has not been carried out on these units, but Scott's observations are consistent with a turbidite origin for at least part of these sediments.

The depositional age for these units is not known. An early Aphebian age is possible and might be related to rifting between the Slave and Superior cratons. However, the underlying Tazin Group is probably Aphebian in age (Sibbald and Lewry, 1980), at least in part. Thus, an early Hudsonian origin for the Thluicho Lake Group is more likely. Hudsonian tectonism decreased markedly west of the Virgin River - Black Lake Shear Zone (Figure 3) (Lewry, Sibbald and Rees, 1978) and, consequently, marine deposits may be expected in this area as a sedimentary record of the major uplifts to the east. In this case, the Thluicho Lake Group and the Ellis Bay Formation would be analogous to either the Cretaceous marine units of the Plains in their relation to the Nevadan-Laramide uplifts in the Cordillera or the Flysch units of the northern Alpine foredeep. Detailed sedimentological analysis involving paleocurrent studies in the Thluicho Lake sediments should help to choose between these hypotheses.

As Scott (1978) did not formally name the component units of the 'Thluicho Lake Group' as formations, the name should technically be amended to Thluicho Lake Formation. However, a review of the Thluicho Lake Group is beyond the scope of this report.

Late Hudsonian Wrench Fault Basins: the Martin Formation and Related Deposits

In northern Saskatchewan, small, late Hudsonian, unmetamorphosed redbed units are scattered over a wide area. These folded and faulted sediments unconformably overlie the metamorphic basement and lie in fault-bound basins. Only part of one basin has been studied in detail thus far: the Martin Formation in the Uranium City area (Tremblay, 1972). Similar deposits are present around Tazin Lake and between Tazin lake and Lake Athabasca (Hale, 1954b; Scott, 1978). A series of redbed deposits occur along the northern shore of Lake Athabasca, from the islands of Crackingstone Peninsula west to northeast Stewart Island, parts of Johnston Island, Gruchy Island, Charlot point, Slate Island, areas near Maurice Bay and the Alberta border (Figure 1). These have commonly been regarded as part of the Athabasca Formation.

Fraser (1953, 1960) considered all unmetamorphosed rock of Crackingstone Peninsula to be part of the 'Athabasca Series'. He regarded the conglomerates on Gruchy Island and those on Stewart Island as similar enough to place both in the same 'conglomerate' subdivision of his Athabasca series.

Bell (1961, 1962a, 1962b, 1963) remapped the same area on a more detailed scale, adopting the term 'Athabasca Formation' for the sandstones and conglomerates on the islands south of Crackingstone Peninsula. He placed the conglomerates on Stewart and Johnston Islands in a 'basal breccia member' of the Athabasca Formation, but regarded the conglomerates of Gruchy Island and neighbouring Gruchy Point as part of the 'Martin Formation' which he considered either 'upper members of the Athabasca Formation' or belonging to the 'late Archean'. Bell left the terms 'Athabasca' and 'Martin Formation' undefined, referring readers to Fahrig (1961) for definitions. He was apparently unaware that Gussow (1957, 1959) had published the stratigraphic scheme for these units which Fahrig later used with minor amendments, including the names 'Athabasca Formation' and 'Martin Lake Series' (amended by Fahrig to 'Martin Formation' - he distinguished these from the low grade metamorphic rocks of the Thuicho Lake Group and placed the latter with the high metamorphic grade rocks of the Tazin Group).

The only difference between the Gruchy Island conglomerates and sandstones and Bell and Fahrig's basal breccia on Stewart Island is the greater thickness and steep dip (70^{o}-90^{o}) of the Gruchy Island sediments. Lithologically, both are strongly altered polymict conglomerates and sandstones. Similar variation in dip and

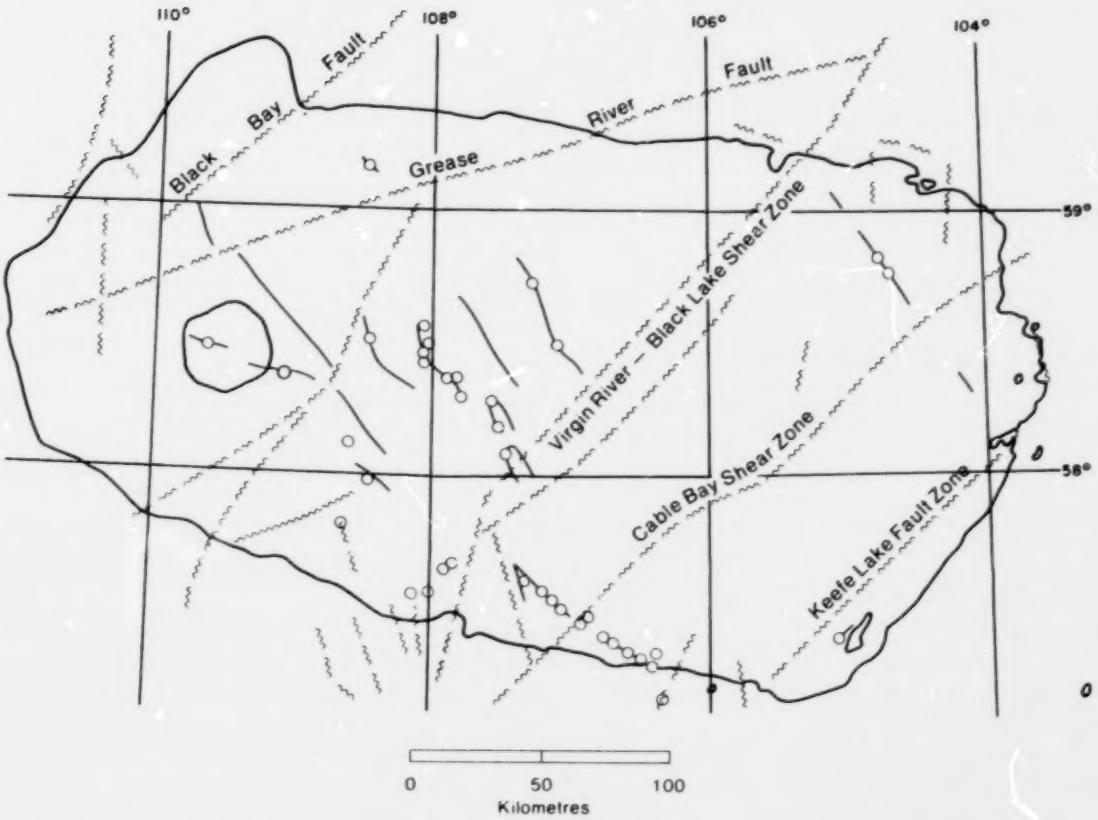

Figure 3 – Major faults and shear zones, dyke outcrops, and magnetic lineaments indicating the presence of dykes in the Athabasca Basin.

thickness is found in the Martin Formation conglomerates in the Eldorado area where thin remnants of the Martin conglomerates at the Ace-Fay minesite lie horizontally only a few miles away from the near vertical dipping base of the Martin Formation at Beaverlodge Lake. The Gruchy and Stewart Islands conglomerates differ strongly from the flat-lying Athabasca Group sediments of the area in that the latter were deposited as quartz rich, well-sorted sandstones in a depositional environment vastly different from the polymict conglomerates, which contain boulders up to 1 m in diameter. Thus it seems more reasonable to regard the conglomerates of Gruchy, Johnston and northeast Stewart Islands as a Martin-type redbed, if not outliers of the Martin Formation itself.

The Gruchy Island rocks are dipping near vertical along the western side of the Black Bay Fault. The bay itself is up to 120 m deep, whereas the remaining 90 percent of Lake Athabasca is generally less than 30 m deep. The same topographic relationship holds in the Martin Lake Basin where the steeply dipping basal Martin Formation forms a resistant ridge and much of the higher strata has been excavated by glaciation to great depth, leaving Beaverlodge Lake as an anomalously deep lake in the area. Thus topography and the structure of the Martin Formation outcrops west of the Black Bay Fault suggest that Black Bay is, or was, underlain (prior to the Pleistocene) by Martin Formation type rock. This leaves the redbeds of Black Bay and the comparable Martin Lake Basin on opposite sides of the Black Bay Fault. Perhaps detailed paleocurrent work in both basins will resolve whether they formed separately or originated as one basin now separated by left-lateral movement along the Black Bay Fault.

Boulders of red, polymict, calcite-cemented fine and coarse clastics identical in composition to sediments of the Martin Formation are common in some localities in northeastern Saskatchewan and suggest the presence of small undiscovered redbed units in this area.

In the Virgin River - Black Lake Shear Zone and the Cree Lake Zone late Hudsonian redbeds are missing.

As this is an area of exposed Hudsonian high-grade metamorphic rock, their absence is probably due to a greater degree of unroofing. In the Virgin River - Black Lake Shear Zone a number of weakly metamorphosed intrusives of Late Hudsonian age, such as the Junction Granite, age 1745 Ma and the Chipman Sills (Gilboy, 1980; McDonald and Broughton, 1980), occur (Figure 1). These may well represent the intrusive roots of wrench fault basins that are exposed at a higher crustal level in less disturbed redbed basins such as the Martin Lake Basin in the Uranium City area.

This basin is infilled with the Martin Formation, composed of about 5000 m of breccias, conglomerates, arkoses, siltstones and basic volcanics, and intruded by gabbroic dykes and sills. Paleocurrent measurements (Tremblay, 1972, Figure 7) show that sediments in the Martin Lake Basin were derived from both sides of the basin and suggest that the basin was not much larger than it is now. The lithology of the basal conglomerates reinforces that conclusion (Fraser *et al.*, 1970). The depositional environments in these redbeds range from talus slopes, alluvial fans and braided streams to lacustrine.

Scott (1978) shows that details of sedimentation, paleocurrent directions and diagenesis vary somewhat in the different redbed deposits, again suggesting the existence of separate basins. For example, the Charlot Point Formation (Langford, 1980), formerly included in the Martin Formation (Scott, 1978) or the Athabasca Formation (Fahrig, 1961), may be distinguished from the type Martin by the presence of red siltstone clasts in the polymict assemblage. These clasts are presumed by Langford to have been derived from the lower part of the Martin Formation and hence, he regards the Charlot Point Formation as younger than the Martin Formation. However, a derivation of these siltstone clasts from underlying argillites of the Thluicho Lake sediments is a distinct possibility. The siltstone clasts in the Charlot Point Formation were well indurated at the time of deposition (as witnessed by their size relative to the associated quartzite cobbles); the Thluicho Lake sediments contain abundant argillites; the redbeds all show evidence of very local derivation (Tremblay, 1972; Scott, 1978) and the Charlot Point Formation clasts seem richer in chlorite than the type Martin Formation (compare Tremblay, 1972; Macey, 1973; Scott, 1978). Erosion and reworking in an oxidizing environment, followed by 1600 Ma of diagenetic changes, could easily have altered part of the chlorite and biotite of the green Thluicho Lake argillites to the red and tan iron oxides of the Charlot Point Formation clasts. This process would have occurred in the type Martin where most mafic minerals have been altered, thereby liberating the red iron oxides (Macey, 1973).

At Slate Island, where the redbeds also unconformably overlie Thluicho Lake Group sediments (the Tazin or Martin sediments of Donaldson), the redbeds also include siltstone clasts, suggestive of similar derivation. These conglomerates, described by Donaldson (1968) as belonging to the Athabasca Formation, were probably deposited in a redbed basin similar in age to the Martin Lake in that their lithologic composition and sedimentary structures differ sharply from the overlying Fair Point Formation (Ramaekers, 1979a) of the Athabasca Group.

Beds of uncertain stratigraphic position in the Maurice Bay area (Harper, 1979) may represent remnants of another basin equivalent in age to the Martin Lake, as they contain the usual unmetamorphosed polymict conglomerates. The matrix is largely quartz grains and amygdaloidal or vesicular grains containing abundant microliths and shard-like structures. The non-quartz grains are largely replaced by calcite, making identification difficult, but their internal structures suggest a volcanic or pedogenic origin. Here also, siltstone clasts are present in these conglomerates as are Thluicho Lake Group sediments (Harper, 1979).

At northeast Stewart Island and at Gruchy Island, thick, polymict interbedded sandstones and debris flows suggest depositional environments similar to those of Martin Formation rather than those of the Athabasca Group.

The age of the Martin Formation is late Hudsonian. The included volcanics have given a K-Ar of 1630±180 Ma (Fraser *et al.*, 1970). Evans and Bingham (1373), by incorporating their paleomagnetic data with the published radiometric ages, suggest an age of 1730 - 1830 Ma for the Martin Formation. They also established that the hematization preceded the folding, and thus must have taken place almost immediately after deposition.

The physical dimensions of the redbed basins, character of their sediments and included igneous rocks, location relative to the Hudsonian uplifts, formation in the closing phases of the Hudsonian orogeny, close association with major faults and structural complexity all suggest an origin as pull-apart basins associated with wrench faulting, similar to that described by Crowell (1974) for southern California, or by Steel (1976) for the Devonian of Norway. Major wrench faults may be expected along a continental suture in order to accommodate the lateral component of movement at the plate junction. This interpretation of basin development seems more plausible than a short-lived phase of rifting, which would require dramatic, unexplained changes in mantle circulation.

Modern analogues to the Saskatchewan redbed basins in plate tectonic setting, sedimentation, and time relationships relative to the major orogenic events can be found in the valleys of the Rocky Mountains. For example, in the Flathead Valley Graben of southwestern British Columbia (Price, 1965) the Oligocene Kishenehn Formation displays the same diversity in lithologic types and sedimentary environments in the same structural setting as does the Proterozoic Martin Formation of Saskatchewan.

In a wrench fault environment, the stratigraphy in contemporaneous, nearly adjacent basins is often dramatically different (e.g. Steel, 1976). Similarities and differences in the basin fill reflect details of tectonic history and of source area, and do not provide a basis for age relationships between the various basins. This appears to be the case in northern Saskatchewan where some

redbed sequences begin with siltstones and arkoses rather than conglomerates (Scott, 1978). Thus, the age of the Charlot Point Formation may be considered to be roughly equivalent to that of the Martin Formation rather than younger as suggested by Langford (1980).

The presence of separate redbed basins means that the name 'Martin Formation' should be restricted to the heterogeneous sediments of the Martin Lake Basin until this complex deposit, representing a variety of mappable rock types (six clastic lithostratigraphic units were mapped by Tremblay, 1972), is better studied, subdivided, and raised to group status. The designation of the Charlot Point area redbeds as the Charlot Point Formation (Langford, 1980) is a first step in the unravelling of the area's Late Hudsonian history.

Paleohelikian Cratonic Basins: the Athabasca Group

A period of instability followed the orogenic phases of the Hudsonian and a series of possibly epeirogenic uplifts and subsidence occurred in northern Saskatchewan. Stratigraphic work (Ramaekers, 1979a; 1980a) has shown the seismic study of Hobson and MacAuley (1969) to be qualitatively correct in that three northeast trending sub-basins divide the Athabasca Basin (Figure 4). Basin formation probably created some northwest trending faults and shear zones and reactivated the major Hudsonian northeast trending zones (Figure 3). The tectonic activity and associated sedimentation resulted in a series of largely transgressive deposits, the remains of which form the Athabasca Group.

Sub-Athabasca Regolith

The basement underlying the Athabasca deposits was intensively weathered prior to sedimentation. The paleoweathering profile, up to 50 m of which is preserved, typically has characteristics of the lower levels of present day laterites (Hoeve, 1977; Hoeve and Sibbald, 1978). A mineralogical zoning with kaolinite in the upper levels and illite and some chlorite in the lower levels is common. Hematitic red staining is pervasive except at the base, and the profile is variably affected by reduction which has removed hematite and emplaced chlorite in the upper levels. Reduction has also affected the overlying Athabasca sandstones and conglomerates (Ramaekers and Dunn, 1977).

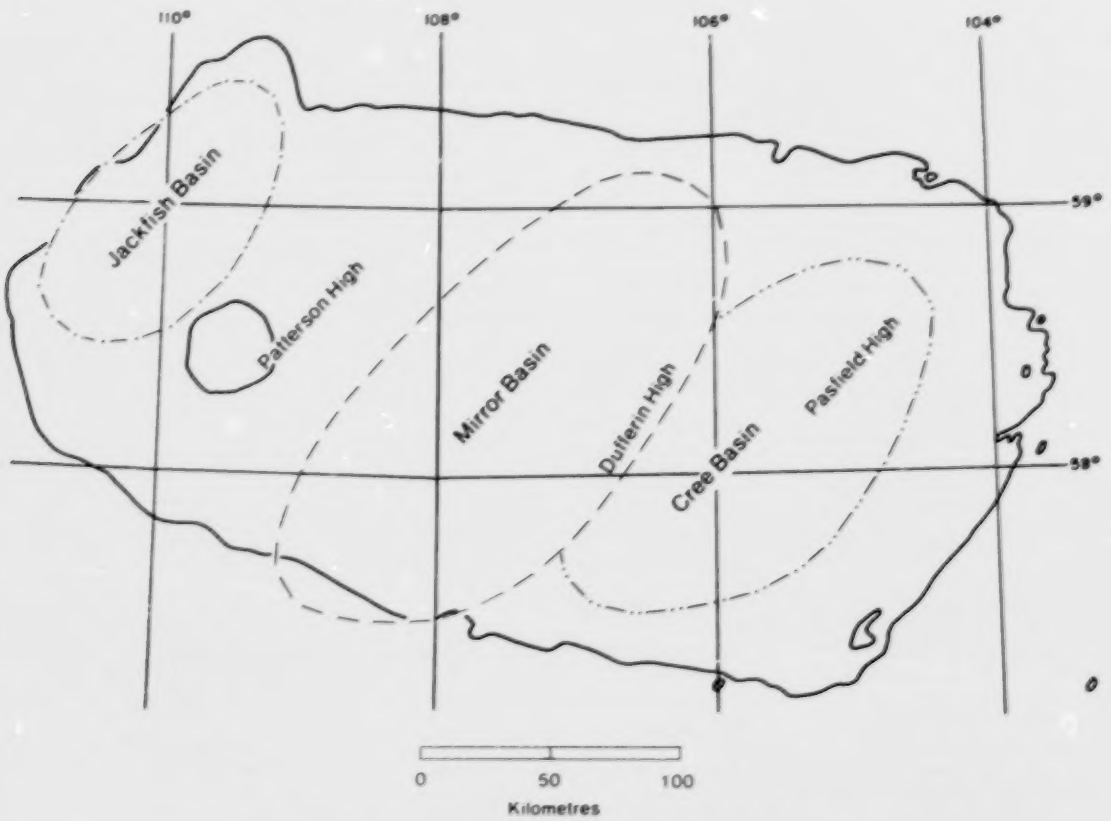

Figure 4 – Sub-basins in the Athabasca Basin

The time at which the regolith formed is not known precisely. It formed in part on rock metamorphosed to upper amphibolite metamorphic grade (sillimanite, garnet, cordierite suite - Winkler, 1967) during the Hudsonian and thus postdated the metamorphic events at least by the time needed to erode 15,000 m of rock. Fahrig *et al.* (1978), suggested dates of about 1550 Ma for regolith formation, based on a paleomagnetic study of unoriented regolith samples, and a date of 1631 Ma based on Rb/Sr isochron work on basement core samples from the Virgin River - Black Lake Shear Zone, a major tectonic zone. Fahrig's paleomagnetic date recorded the age of hematite diagenesis (Ramaekers, 1979d, 1980b; this report, section on diagenesis). The radiometric date is based on samples taken from a major late Hudsonian shear zone, intruded by late Hudsonian granites (Junction Granite, 1974 Ma; Bell and Blenkinsop, 1980) and the Chipman Sills (Gilboy, 1980). In attempting to date the alteration, however, the most severely altered samples were not analyzed isotopically nor used in the isochron. Of the samples used, the one most intensely altered fell below the isochron, suggesting a younger age. The data used by Fahrig clearly suggest that the 1631 Ma date obtained from a selection of his samples does not refer to the alteration event causing the intense chemical alteration and giving isotopic determinations that fall below the isochron line. Evidently the intense weathering postdates the 1631 Ma event.

Basal Conglomerates

At least five types of conglomerate may occur at the lower contact of the Athabasca Group, and they differ widely in origin and age. As discussed previously, a number of the 'basal Athabasca conglomerates' of various authors are Late Hudsonian sediments deposited in a tectonic setting different from that of the Athabasca Group and are perhaps up to 200 Ma older. Included in these are the conglomerates on Slate Island, Charlot Point and on the islands bordering Crackingstone Peninsula.

The regolith below the Athabasca Group is conglomeratic in some localities. The conglomerates are lag deposits produced by winnowing and minor reworking of the upper layer of the regolith and their lithology reflects that of the underlying rock. They are best developed (1 to 2 m thick) where they overlie pelitic rocks with large quartz segregations (e.g. at Newham Lake), but are more commonly thin and discontinuous. By comparison with modern analogues, their age may be considerably greater than that of the Athabasca Group.

In places (e.g. the Maurice Bay area), the regolith and bedrock are reworked into thin, debris flow deposits with a quartz sandstone matrix and may be interbedded with strata of the Athabasca Group. As debris flows also occur in the Late Hudsonian basins underlying these areas, identification of those in the Athabasca Group may be difficult unless associated with angular unconformities. These flows may be related to the tectonism that initiated the Athabasca sub-basins prior to deposition of the major deposits and burial of bedrock relief. Regolith material is less commonly found to be sorted, transported and incorporated into units of the Athabasca Group.

A number of the major basal beds of the Athabasca Group are conglomeratic in whole or interbedded with sandstone. Clasts in these units are typically well rounded and relatively well sorted.

Minor Units and Formation Contacts within the Athabasca Group

Although the contact of the basement with the Athabasca Group is generally depositional, fault contacts are common. Debris flows in the vicinity of the fault contacts suggest that at least some of this faulting was syndepositional. Post-depositional faults appear to be more common, but their extent and number are probably underestimated due to poor exposure of fault zones. Formational contacts within the Athabasca Group are almost nowhere exposed. Their nature is generally inferred from the lithofacies sequence and pebble types contained in the overlying units.

At the basement and at unconformities within the group, thin local units that indicate a sedimentary environment different from that of the adjacent strata may occur. They represent deposition controlled by local relief. An example is the clay-rich unit showing intermittent dessication (intertidal or fluvial environment?) that overlies basal debris flows of the Athabasca Group in the Maurice Bay area (Harper, 1979; Mellinger, 1980). Similarly, fluvial units in the eastern part of the Athabasca Basin show paleocurrent patterns at the basal contact that vary dramatically from the uniform trends above. Likewise, thin clay-rich units occur in some borehole cores at or near the contacts of the fluviatile units, suggesting the presence of short-lived coastal lagoons. These units are not mappable at scales of 1:250,000 and are not shown on the maps accompanying this report. Instead, they are included with the lithologically most similar stratigraphic unit.

The Athabasca Basin is known only at the reconnaissance level. The major lithostratigraphic units have been mapped and a paleogeographic reconstruction is possible, but detailed mapping in conjunction with drilling programs will undoubtedly delineate other minor stratigraphic units. Shorelines may have migrated more than the present study suggests and thin tongues of fluvial material may be preserved in the marine section and vice versa. Mapping these features in the absence of fossils will be difficult.

Major Stratigraphic Units of the Athabasca Basin

The Athabasca Group

The name 'Athabasca Group' (Ramaekers, 1979a) was proposed for the unmetamorphosed, flat-lying and little disturbed sediments of Helikian age outcropping in Alberta and Saskatchewan from the north shore of Lake Athabasca and the Fond-du-Lac River east to Wollaston Lake and south to Cree Lake. The group is composed largely of sandstones with minor siltstones, shales, conglomerates and carbonates. It includes the 'Athabasca' and 'Carswell' Formations of Fahrig (1961), and the conformably intervening Douglas Formation, which was named informally and described briefly by Amok (Canada) Ltd. (1974) and Harper (1978).

Here, the Douglas and Carswell Formations are included in the Athabasca Group because, along with the underlying conglomerates, sand, silt, and mudstones (McConnell's, Sproule's, Gussow's and Fahrig's 'Athabasca sandstones'), they form a middle Helikian, conformable, unmetamorphosed sequence. This sequence is distinguishable from the underlying Archean, Aphebian and possibly early Helikian units by metamorphic grade, profound angular unconformity, tectonic style, and sedimentary environment. A disconformity representing a hiatus of over 1000 Ma separates the Athabasca Group from overlying Devonian and Cretaceous clastics and carbonates.

This arrangement agrees with the usage of McConnell's (1893) term 'Athabasca sandstone' to distinguish between sediments of the Athabasca Group and the metamorphosed basement. It also agrees with Blake (1956) in that the carbonates are treated as a subunit of the Athabasca sandstones, and with Gussow (1957, 1959) in that the stratigraphic break between the carbonates and the rest of the Athabasca Group is recognized as being less important than the angular unconformity (and differences in depositional environments) between the Athabasca Group and the Martin Formation. Fahrig (1961) regarded the Carswell, Athabasca and Martin Formations as being of equal stratigraphic rank, thereby giving due recognition to the distinctiveness of the Carswell Formation, but obscuring the magnitude of the stratigraphic break below the Athabasca Group.

The Athabasca Group is divided here into two subgroups: the lower William River Subgroup (Ramaekers, 1980a) comprising the Fair Point, Manitou Falls, Lazenby Lake, Wolverine Point, Locker Lake, Otherside, and Tuma Lake Formations; and the upper Points Lake Subgroup (new name), which includes the Douglas and Carswell Formations (Table 1). This subdivision facilitates the mapping of tectonically disturbed areas and the description of glacial erratics of the Athabasca Group. Profound changes of depositional environment occur in the William River Subgroup because the fluviatile-marine boundary is crossed several times within this sandy sequence. Division of the Athabasca Group into a fluviatile and a marine subgroup has a certain appeal, but would be difficult to define purely on lithologic criteria. It would be of little use mapping under the best of conditions, be impossible to apply in tectonically disturbed areas and would not help much in describing sandstone erratics.

Although similar in appearance and found in tectonically disturbed areas such as the Carswell Structure, the formations of the William River Subgroup are difficult or impossible to identify, yet remain distinctive as a group. The William River Subgroup corresponds essentially to the 'Athabasca Formation' of Gussow (1957, 1959) and Fahrig (1961) except that they included the few then known outcrops of the Douglas Formation.

The Points Lake Subgroup, as defined here, is preserved only in the Carswell Structure and is composed of the fine-grained clastics of the Douglas Formation and the overlying dolomitic Carswell Formation. It is named after Points Lake within the Carswell Structure. Almost all of the rock of the Points Lake Subgroup is identifiable at the formation level, even in isolated hand specimens. Both units of the subgroup were deposited in organic-rich environments with relatively little or no clastic input compared to the William River Subgroup sediments. The subgroup boundaries reflect a pronounced change in depositional environments relative to the underlying units, probably due to decreased tectonism in the region.

The William River Subgroup

The most useful mapping criteria for the clastics of the William River Subgroup were found to be the distribution of maximum grain sizes and the thickness and frequency of occurrence of bedded silt and mudstone layers. Maximum grain size was taken to be the average of the largest apparent diameters of the 10 largest clasts found on an outcrop, or the largest apparent diameter of the single largest clast in a 1.5 m section of core. These outcrop and core methods for determining maximum grain size were found to give approximately equivalent results in the few cores collared in outcrop. Colour varies dramatically and erratically within the same unit, due largely to the long diagenetic history of the iron oxides within the Athabasca Basin, and was therefore ignored in defining these formations.

William River Subgroup Undifferentiated

Currie (1969) subdivided the Athabasca Group clastics within the Carswell Structure into a lower, red hematized conglomeratic member and an upper, white, clean, finer grained quartz sandstone member. His diagenetic criterion (red, hematized) is a function of porosity and tectonic history and conflicts in detailed mapping with his genetic criterion (texture). Ramaekers (1979a, 1980a) noted the presence of five pebbly formations within the Athabasca Group, all of which may occur in the Carswell Structure. It seems highly unlikely that Currie's basal pebbly member is the same stratigraphic unit throughout, considering the extreme tectonic disturbance of the sandstones within the Carswell Structure.

Currie's basal member is probably composed of parts of the Fair Point, Lazenby Lake, and Locker Lake Formations, placed in various degrees of juxtaposition and variously interbedded with parts of the finer grained formations. More drilling and detailed mapping of the sandy clastic units of the Athabasca Group within the Carswell Structure are needed before the William River Subgroup can be reliably differentiated here.

Fair Point Formation

Definition, Distribution, and Thickness:

The Fair Point Formation (Ramaekers, 1979a) forms the base of the William River Subgroup in the western Athabasca Basin (Map 2) and is largely restricted to the Jackfish Sub-basin (Figure 4). It unconformably overlies highly metamorphosed Archean and Aphebian strata and erosional remnants of the Thluicho Lake Group and Late Hudsonian redbeds. The Fair Point Formation reaches a maximum thickness of about 400 m (Figure 5). Limited core data suggests that it may thicken to the south and west. Core study shows it to be overlain disconformably by the Manitou Falls Formation, at least in the eastern half of the Jackfish Sub-basin (Figure 6, Section 1,7 in pocket).

The type section is the exposure on the northwestern shore of Lake Athabasca just south of the eastern tip of Fair Point (NTS mapsheet 74N-5; UTM coordinates 561800 m E., 6578500 m N.). The designated parastratotype is the core section from 756 m to 916.5 m from Canadian Southern Petroleum core 2-1, NTS mapsheet 74K-13, which provides a continuous core through the upper half of the formation.

The Fair Point Formation includes the 'Fidler Point sandstones' of Gravenor (1959), who was the first to realise their distinctiveness. The Fair Point outcrop was chosen as type section for the formation because it is better exposed than Gravenor's isolated outcrops at Fidler Point. Also, other Fair Point Formation outcrops and many boreholes are available near the type outcrop, showing the complete range of facies present in the unit. The Fair Point Formation is taken to include both the 'Lower' and 'Upper Sequence' of Mellinger (1980). The 'Lower Sequence' is very local (discussed

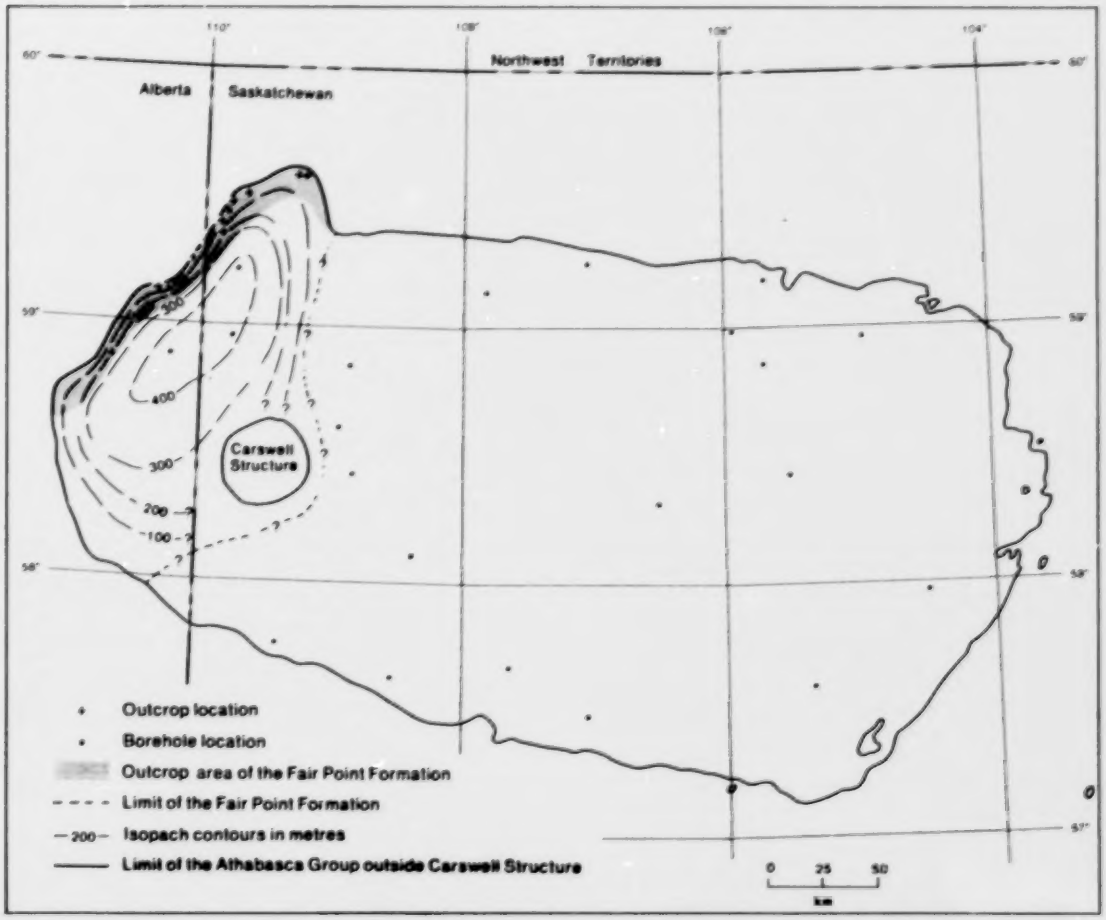

Figure 5 – Isopach Map of the Fair Point Formation

previously in this report under 'Minor Units') and is appended here to the Fair Point Formation until these facies prove mappable.

Lithology:

Nearly all rock of the Fair Point Formation consists of an easily distinguishable pebbly sandstone with large, well-rounded quartz pebbles and smaller, more angular, altered mafic clasts disseminated along bedding planes. Pebbles may be up to 10 cm in diameter. The quartz sandstone has an abundant clay and hematite matrix. Clay occurs as discrete grains, probably pseudomorphs of feldspar, and in grains interlaminated with hematite, probably pseudomorphs of biotite. Clay also occurs as interstitial matrix, well crystallized along microstylolitic seams, and as fracture fillings - probably altered fault gouge and/or hydrothermal precipitation. It is rarely present as a diagenetically recrystallized bedded clay. Kaolinite is the dominant interstitial clay; illite is also present in the other modes of occurrence. Siderite is typically present, particularly near faults. It forms along lamellar primary pores and displaces cements and some detrital grains. Siderite may show signs of later decarbonatization and forms considerable secondary porosity filled in part with euhedral hematite.

At the base of the formation in the Maurice Bay area, thin conglomeratic beds are present. They are interbedded with better sorted sandstones, thin mudstones and, in some places, grade into mudstones. These were first reported by Harper (1979) and form the upper part of the 'Lower Sequence' of Mellinger (1980). They overlie even more restricted, discontinuous, unsorted, matrix-supported conglomerates and breccias [the 'fanglomerate' of Harper (1979) and the basal section of the 'Lower Sequence' of Mellinger (1980)]. At Lobstick Island, 12 km northeast of Maurice Bay, very well-sorted fine-grained sandstones containing a few scattered large pebbles and cobbles occur near the base of the Fair Point Formation.

The Fair Point Formation is characterized by higher readings on gamma ray logs relative to the overlying Manitou Falls Formation and shows a gradual decrease upwards across the formational boundary.

Manitou Falls Formation

The Manitou Falls Formation (Ramaekers, 1979a, 1980a) is the only formation of the Athabasca Group present in the eastern half of the Athabasca Basin. It is informally subdivided here as follows:

1) a basal series of interbedded, probably fluviatile and marine conglomerates and sandstones (MFa) largely confined to the Mirror Sub-basin (Figure 4);
2) a basal fluviatile conglomeratic member (MFb) largely confined to the Cree Sub-basin (Figure 4);
3) a middle, relatively clean sandstone member (MFc);
4) an upper clay intraclast-rich member (MFd).

The last two members are found throughout the Athabasca Basin.

The type section is the exposure 1.5 km west of Manitou Falls on the north shore of the Fond-du-Lac River (NTS mapsheet 74I-16) in the MFc member. No single exposure shows all facies of the Manitou Falls Formation, thus, reference localities are designated outcrops 1.5 km east of Pasfield Lake in the MFd member (NTS mapsheet 74I-6; UTM coordinates 489100 m E., 6467400 m N.), and about 1 km west of Cunning Bay, Wollaston Lake in the MFb member (NTS mapsheet 64L-5; UTM coordinates 578700 m E., 6473600 m N.).

MFa Member of the Manitou Falls Formation

Definition, Distribution and Thickness:

Sparse outcrop and drill core in the Virgin River - Mirror River area (NTS sheets 74F, 74G) suggests that an interbedded marine and fluviatile sequence up to 600 m thick (Figure 6, Sections 2, 3, 4, 7) underlies the fluviatile tongue of the Manitou Falls Formation (MFb, MFc, MFd). Marked differences in paleocurrent directions between outcrops, the great amount of convoluted bedding (much more than is evident in the rest of the Manitou Falls Formation), and the disseminated distribution of the component pebbles suggest a dominantly marine sequence. The MFa member should eventually be subdivided into several formations, however, it remains in the Manitou Falls Formation because it has not been possible to delineate distinct strata with any degree of confidence thus far. Occurrences of pebbly erratics at about the same stratigraphic level in the Cree Sub-basin suggest that a marine tongue of this unit may extend east as far as Close Lake (74H mapsheet).

In the central Mirror Sub-basin the MFa member extends below the fluviatile members of the Manitou Falls Formation (Figure 6, Sections 2, 3, 4, 7; Figure 7). Without paleocurrent data and outcrop information it becomes difficult to differentiate between the MFa and MFc members. Compounded by the lack of deep drill holes in the interior of the Athabasca Basin, this leads to poor definition of the boundary of the MFa member in the subsurface.

The MFa member does not reach the northern edge of the basin (Figure 6, Section 3), but it is tentatively identified in the Gulf Rumpel Lake borehole on the basis of variations in maximum grain size and an increase in the percentage of illite in the interstitial clays. It is possible that some of the marine units of the MFa member will prove correlatable with the Fair Point Formation in the Jackfish Sub-basin across the Patterson High (Figure 4).

Lithology:

The Canadian Southern Petroleum borehole 6-1, in mapsheet 74F, penetrates the bottom half of the MFa member and contains the best available section through that member. The section shows a series of pebbly conglomerates similar to those of the Fair Point Formation, interbedded with cleaner, better sorted sandstones, some of which contain over 1% of clay intraclast-rich layers.

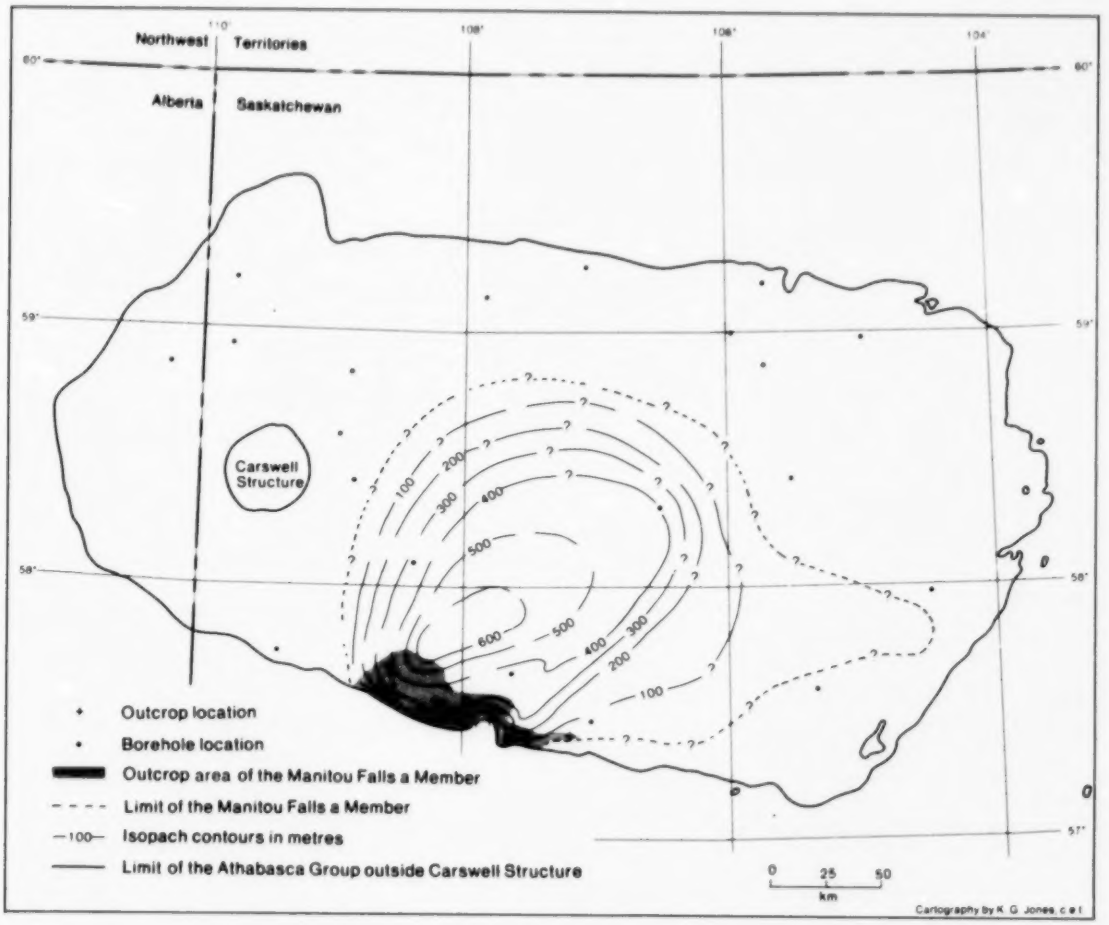

Figure 7 – Isopach Map of the Manitou Falls (a) Member.

Conglomeratic Member of the Manitou Falls Formation (MFb)

Definition, Distribution and Thickness:

The MFb member is defined informally here as consisting of sandstones that are interbedded with at least 2 percent of bedded clast-supported conglomerates found in beds 2 cm thick. Formal stratigraphic nomenclature is avoided here for several reasons: poor definition of boundaries at present; the polygenetic origins of the unit defined here; and the probability that increased drilling will outline distinct conglomeratic bodies and hence justify a more complex subdivision of the Manitou Falls conglomerates.

The conglomerates are friable and poorly exposed due to glacial plucking. Core study shows that they extend further into the basin and higher up the stratigraphic section than outcrop occurrences indicate. Outcrops are found along a belt less than 25 km wide at the eastern edge of the Athabasca Basin, with a few scattered exposures along the north and south rims of the basin (Figure 8). The best exposures are in fault zones where induration by silica and hematite has resulted in a more resistant rock type. Over large areas in the Cree Sub-basin the MFb member consists of two coarse units separated by finer grained beds.

In the Jackfish Sub-basin, the Manitou Falls Formation disconformably overlies the pebbly Fair Point Formation and has formed a thin conglomeratic member of different origin. The Jackfish Sub-basin conglomerates are nowhere exposed.

The MFb member is the basal unit of the Athabasca Group in the Cree Sub-basin and overlies metamorphosed basement rock. Some of the Aphebian meta-quartzites and meta-arkoses are heavily altered in the regolith zone and now consist of quartz grains, hematite, and clays - identical to those constituents found in the Athabasca Group sandstones. This has led to misidentification of the basal contact, for example, in Fahrig *et*

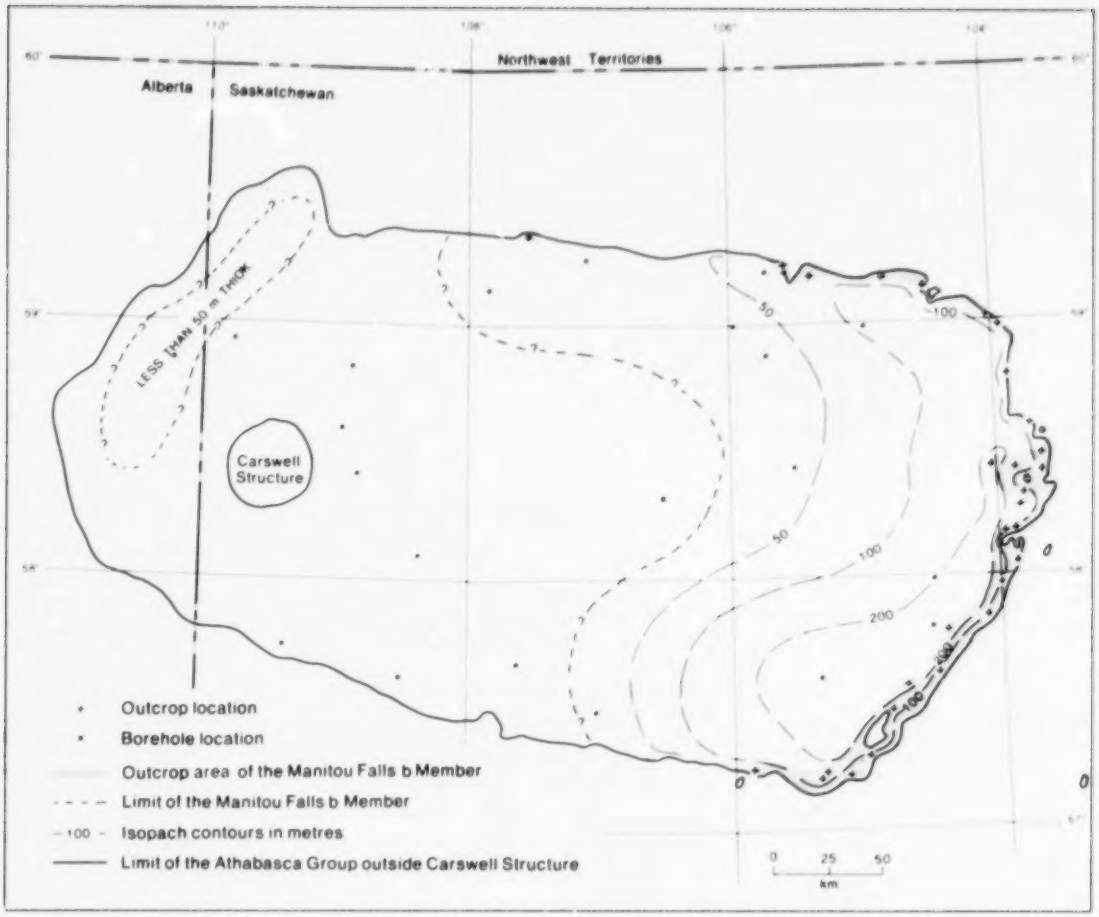

Figure 8 – Isopach Map of the Manitou Falls (b) Member

al. (1978), discussed by Ramaekers (1979d, 1980b). Contacts are largely depositional, but in places are formed by post-Manitou Falls faults, such as at the Rabbit Lake mine site just east of Wollaston Lake.

In the southwest half of the Cree Sub-basin the MFb member thins to the point where it becomes indistinguishable from the basal lag conglomerates. In the northern half of the Athabasca Basin the MFb member thins more gradually and its grain size decreases westwards, but the unit is still recognizable as far west as the Poplar Point area. The upper boundary of the MFb member is always a gradual change to the finer and better sorted sandstones of the MFc member.

In cores, the MFb member is up to 265 m thick in the Cree Sub-basin. A 230 m section is preserved in the Hanson Lake Mines No. 1 drillhole (NTS area 74H-16). The MFb member in the Jackfish Sub-basin is less than 50 m thick.

Lithology:

The MFb member is characterized by the presence of at least 2 percent clast-supported conglomerate beds 2 cm thick or more interbedded with sandstones. These figures allow an arbitrary boundary to be drawn between the MFb and the more homogenous sandstones of the MFc member.

The percentage of conglomerates in the MFb member varies from 2 percent along the western margin to about 60 percent at the base of the unit along the eastern margin of the Cree Sub-basin. In the Jackfish Sub-basin conglomerates rarely form more than 10 percent of the member. Maximum clast size in the conglomerates increases from 4 mm at the distal (downstream) end of the member to a maximum of 160 mm at the proximal (upstream) side. Clasts consist nearly exclusively of quartz - largely polycrystalline and vein quartz. Rose quartz is not uncommon in the Wollaston Lake area and minor amounts of blue quartz, jasper and dark chert

pebbles occur. Large, well-rounded cobbles are found at the base of the MFb member in the Cunning Bay area of Wollaston Lake, and also in some drill holes. The cobbles consist of a porous framework of quartz partially infilled by authigenic clays and/or hematite. Their texture suggests that these are leached remnants of meta-arkosic gneisses. Evidently at least some of these basal conglomerates were polymictic at time of deposition.

The interbedded sandstones are typically poorly sorted, and consist of subangular quartz grains. Polycrystalline quartz, strained and unstrained monocrystalline quartz are most common; microcrystalline quartz with crystal sizes around 20 microns (the upper size limit for chert) generally forms less than 1 percent of the rock. One millimetre thick layers of detrital hematite, typically rich in zircon, occur parallel to bedding and cross-bedding in the basal section. They may be present throughout the MFb member or restricted to as little as the basal 30 m, as in Hanson Lake Mine's No. 1 core. The hydraulically sorted grains in these layers are similar in size to the surrounding quartz grains. Clay intraclasts are rare but may be found even in coarse conglomerates. Interstitial clay content varies from 1 to 25 percent, but typically forms about 7 percent of the rock.

Cements are predominantly silica, as quartz overgrowths, and iron oxides as specular hematite in the conglomeratic zones, overgrowths on the detrital hematite, and commonly as Liesegang bands and red stains along bedding and cross-bedding planes. A limonitic zone, varying greatly in thickness, is erratically present above the basal contact. Tourmaline, zircon and rutile and/or anatase are present, but in very low concentrations. Tourmaline typically has overgrowths.

Representative partial sections from exposures of the MFb member near Otter Bay and Cunning Bay (a parastratotype) east of Wollaston Lake are illustrated in Figure 9.

Clean Sandstone Member of the Manitou Falls Formation (MFc)

Definition, Distribution and Thickness :

The MFc member is defined informally here as consisting of sandstones that lack conglomerate beds thicker than 2 cm and contain less than 1 percent clay intraclast-rich layers. One-layer-thick pebble or granule beds are common in the lower and eastern sections along the boundary with the MFb member. The MFc member is found throughout the Athabasca Basin except at its eastern, south-central and western edges (Figure 10).

The MFc member overlies the MFb member conformably and gradationally wherever this unit occurs in the subsurface. In the Mirror Sub-basin, and probably over the Patterson High (Figure 4), the MFc unit overlies the MFa member, but along the Patterson High it may directly overlie the basement (Figure 6, Sections 1-7). The MFc member has a gradual contact with the overlying MFd strata that is arbitrarily placed where the number of clay intraclast layers and thin bedded mudstones first exceed 1 percent of the strata. The percentage of clay intraclast layers fluctuates somewhat in most areas and, as a result, the MFc - MFd contact is difficult to place without resorting to complex intertongueing relationships. The lack of deep cores in the Athabasca Basin interior precludes a meaningful interpretation of complex boundary relationships at present and thus the MFc - MFd contacts shown in this report were chosen for simplicity. More detailed mapping using the criterion for the boundary defined above will permit precise definition of the fluvial systems of the MFc and MFd members and possibly the reconstruction of the detailed tectonic control of the Athabasca Basin at that time.

The thickness of the MFc member is relatively constant except in the Mirror and Jackfish Sub-basins where it reaches a maximum of about 400 m (Figure 10). Work to date indicates that a major northwest trending graben, in line with the faults exposed at Fidler Point in Alberta on the west shore of Lake Athabasca, formed in the Jackfish Sub-basin at that time. Its extent east of the Carswell Structure is not known due to lack of suitable boreholes.

Lithology:

The sandstones of the MFc member are typically medium to very coarse grained and, less commonly, granule-sized quartz arenites. Their roundness varies from subangular to subrounded, with a few lenses of near-spherical material. Pebbles up to 12 mm in diameter commonly occur in 1 pebble thick layers in the lower units of the member. They decrease in frequency and size towards the west and up-section and consist mainly of polycrystalline and vein quartz with minor jasper, blue quartz and chert.

Bedded clay layers generally 1 - 2 cm thick are present but rare. Clay intraclasts are present, but do not form distinct layers and comprise less than 1 percent of the rock. These angular, white, soft intraclasts are up to 3 x 3 x 0.5 cm in size. In places, they are hematized to red, purple or grey.

Interstitial clay is common as a lining of pores and also as small pellets of the same size and shape as the surrounding quartz grains. Clay typically forms from 0.5 to 15 percent of the rock and averages around 5 percent. The dominant cements are quartz as syntaxial overgrowths and iron oxides. Specular hematite is common, as are red hematitic bands along bedding and cross-bedding planes, and as Liesegang bands. Dense, hard, limonitic Liesegang bands that weather in high relief outcrop are not uncommon. Tourmaline and zircon are generally present in trace amounts. Tourmaline commonly shows overgrowths. Representative partial sections of the member are illustrated in Figure 11.

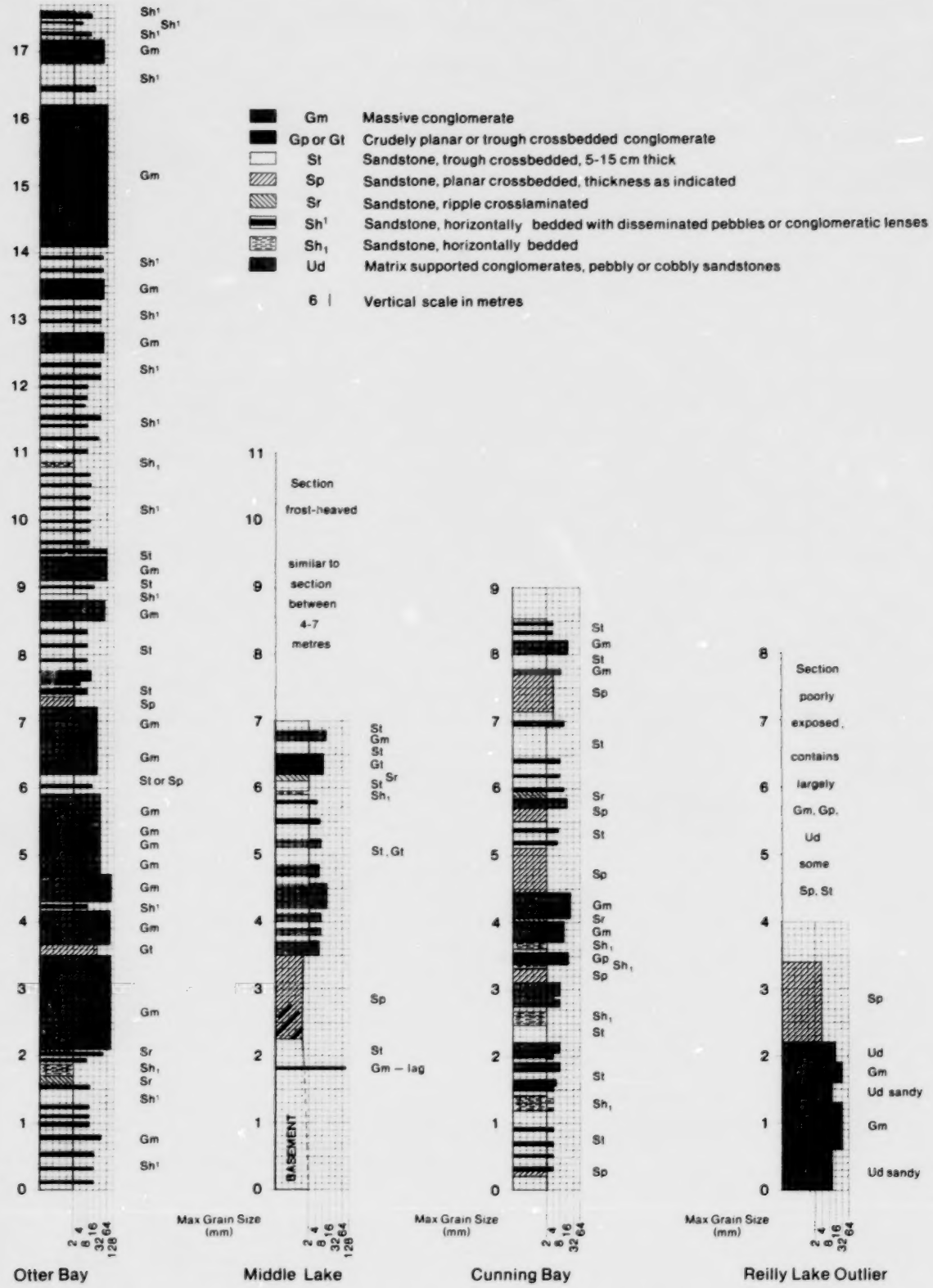
Gm Massive conglomerate
Gp or Gt Crudely planar or trough crossbedded conglomerate
St Sandstone, trough crossbedded, 5-15 cm thick
Sp Sandstone, planar crossbedded, thickness as indicated
Sr Sandstone, ripple crosslaminated
Sh' Sandstone, horizontally bedded with disseminated pebbles or conglomeratic lenses
Sh1 Sandstone, horizontally bedded
Ud Matrix supported conglomerates, pebbly or cobbly sandstones
6 | Vertical scale in metres
Section frost-heaved
similar to section between 4-7 metres
BASEMENT
Section poorly exposed, contains largely Gm, Gp, Ud some Sp, St
Max Grain Size (mm)
2 4 8 16 32 64 128
Otter Bay
Middle Lake
Cunning Bay
Reilly Lake Outlier

Figure 9 – Representative partial sections through the conglomeratic member of the Manitou Falls Formation.

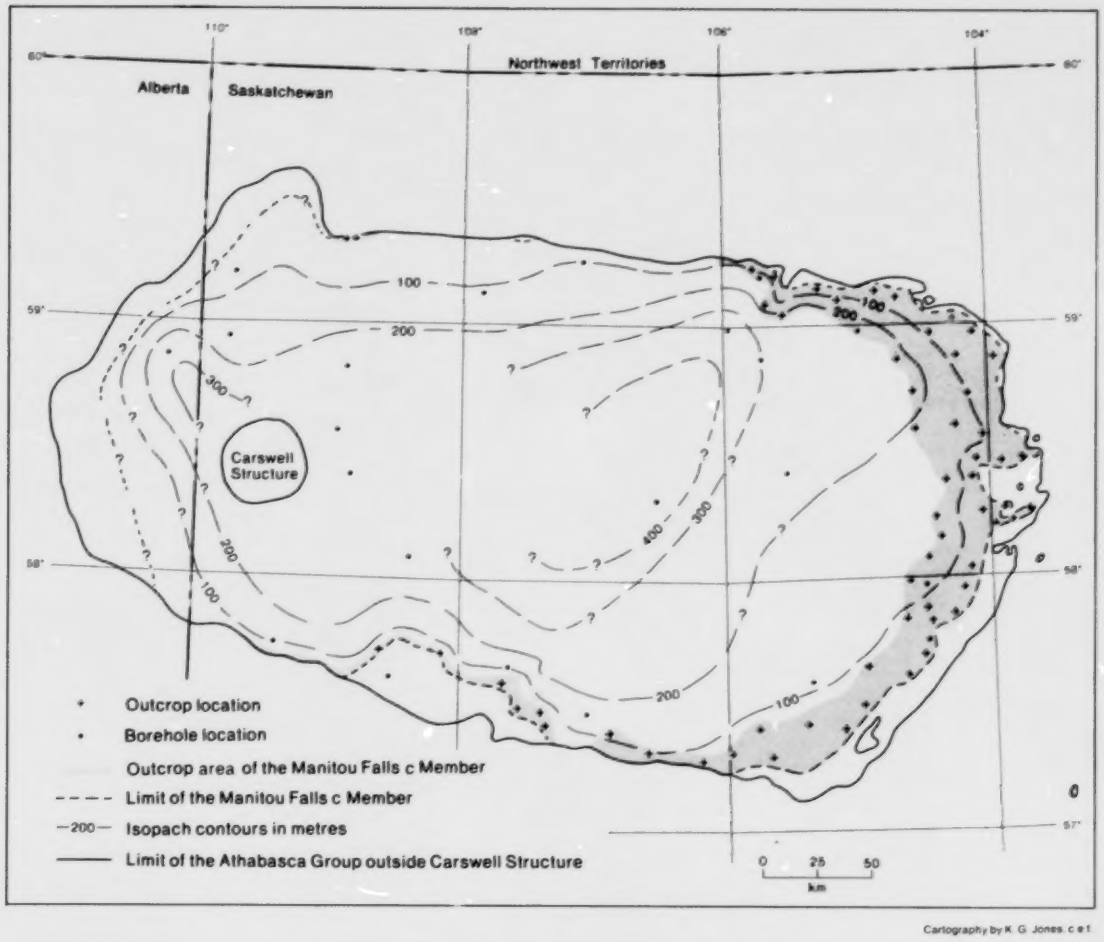

Figure 10 – Isopach Map of the Manitou Falls (c) Member.

Intraclast-rich Member of the Manitou Falls Formation (MFd)

Definition, Distribution and Thickness:

The MFd member (Ramaekers, 1979a) is defined informally here as comprising relatively well-sorted quartz arenites containing greater than 1 percent clay intraclast-rich layers. Bedded silt or mudstone layers are rare and almost always less than 5 cm thick. They are more common in the Jackfish Sub-basin. Very thin (1-2 mm) clay or silt drapes are common. A section through all but the uppermost units of the MFd member is present in Dejour Mines, Wapata Lake core no. 1, from 0 to 374 m. The MFd member is present throughout the entire Athabasca Basin except at the margins (Figure 6, Sections 1-7; Figure 12).

Outcrop is fairly common where the MFd member surfaces in the eastern three quarters of the Athabasca Basin, except for scattered areas along its upper contact which are covered by glacial and periglacial deposits. No exposures of the MFd member are known in the western quarter of the Athabasca Basin. Projections from boreholes suggest that it would reach the surface beneath Lake Athabasca and the thick glacial and lacustrine deposits of the southwestern part of the Athabasca Basin.

The MFd member is always found to overlie the MFc member with a gradational boundary. No exposures of its upper contact are known. It is overlain by the Lazenby Lake Formation (disconformably) in the southwestern half of the Athabasca Basin, by intervening intraclast-free sandstones similar in lithology to those of the MFc member, and by equivalent sandstone beds placed in the Wolverine Point Formation elsewhere. The disconformable nature of the contact is inferred from the sudden appearance of pebbles and the change in the types and frequencies of sedimentary structures between the MFd and the Lazenby Lake Formation. The duration of the period of nondeposition is uncertain. The contact is difficult to identify in outcrop where the Wolverine Point Formation overlies the MFd member because the

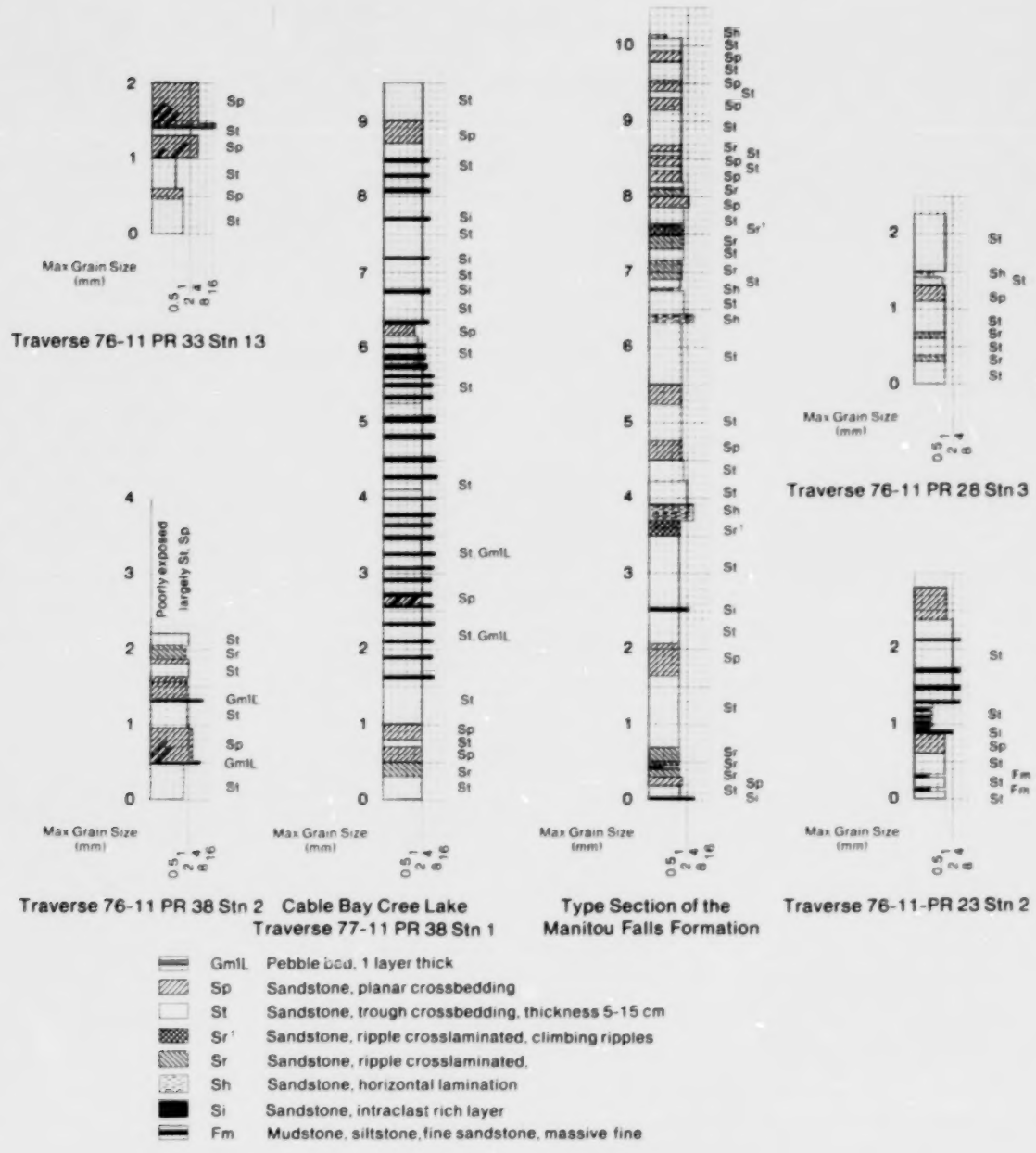
Traverse 76-11 PR 33 Stn 13
Traverse 76-11 PR 28 Stn 3
Traverse 76-11 PR 38 Stn 2
Cable Bay Cree Lake
Traverse 77-11 PR 38 Stn 1
Type Section of the
Manitou Falls Formation
Traverse 76-11-PR 23 Stn 2
Max Grain Size (mm)
Poorly exposed largely St, Sp
GmlL Pebble bed, 1 layer thick
Sp Sandstone, planar crossbedding
St Sandstone, trough crossbedding, thickness 5-15 cm
Sr' Sandstone, ripple crosslaminated, climbing ripples
Sr Sandstone, ripple crosslaminated,
Sh Sandstone, horizontal lamination
Si Sandstone, intraclast rich layer
Fm Mudstone, siltstone, fine sandstone, massive fine

Figure 11 – Representative partial sections through the clean sandy member of the Manitou Falls Formation

bedded clays diagnostic of the former unit weather recessively. The distinction must be made on the basis of the lack of abundant clay intraclasts and sedimentary structures, thereby indicating a marine depositional environment rather than a fluvial setting conditions. Such a distinction requires good exposures, rarely available.

The relatively thin unit of sandstones lithologically similar to the MFc member is found between the MFd member and the Lazenby Lake Formation in the 74F mapsheet. Although the unit is poorly exposed, it may represent a marine shoreline facies and is presently retained in the Manitou Falls Formation.

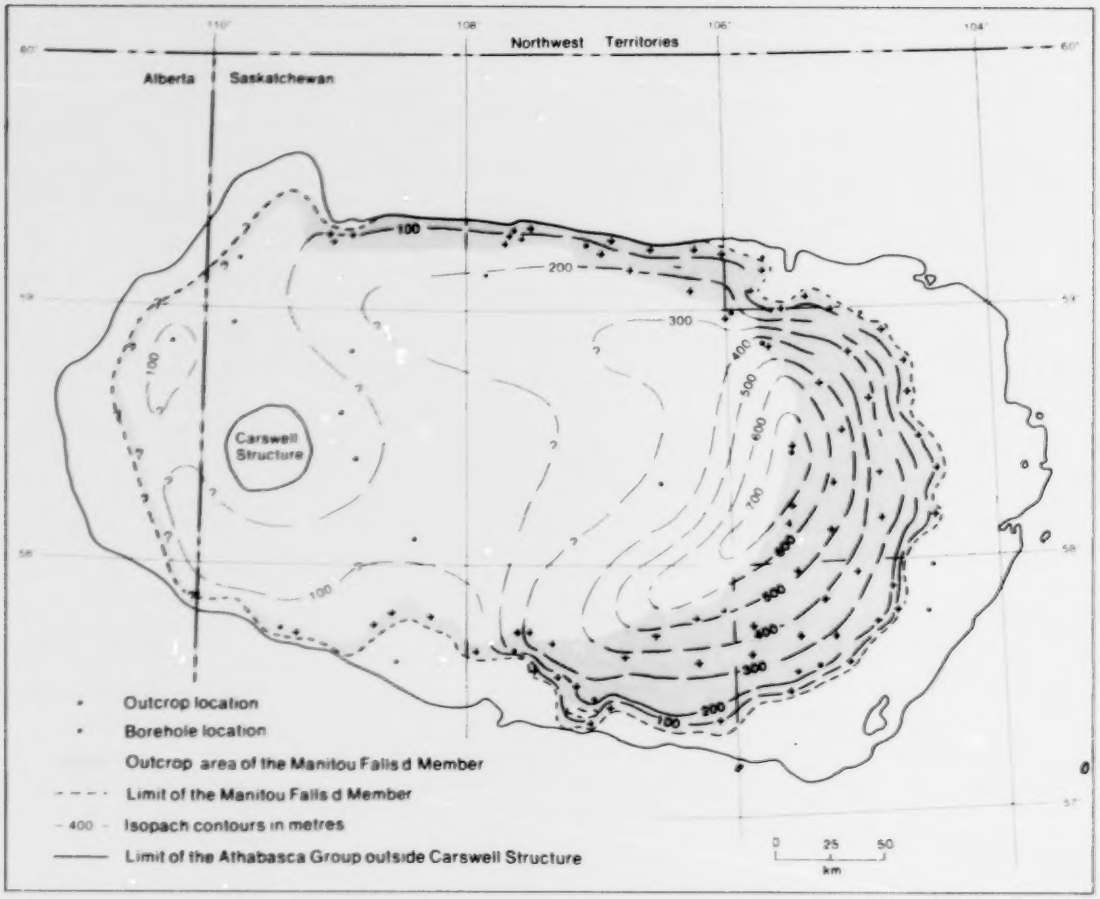

Figure 12 – Isopach map of the Manitou Falls (d) Member.

Extensive outcrop of the MFd member showing vertical sections of about 15 m are present in the canyons east of Pasfield Lake along the northern rim of the Athabasca Basin. They show extensive ripple-marked beds and clay intraclast-rich layers both up-section and laterally. Cross-bedding is often obscured due to thorough sorting and extensive lichen cover. The MFd unit is resistant to erosion and forms drainage divides where it is exposed.

The MFd member reaches a maximum thickness of about 700 m in the Cree Sub-basin and thins dramatically across the Virgin River - Black Lake Shear Zone, indicating a tectonic high (the Dufferin High; Figure 4) at this time relative to the Cree Sub-basin to the east. In the central Jackfish Sub-basin the MFd member thickens along with the underlying MFc member, thus indicating continued subsidence relative to the area to the north.

Lithology:

The MFd sandstones are typically fine- to coarse-grained quartz arenites. One-layer-thick granule or pebble beds, or disseminated pebbles along bedding planes are found in places, especially near the contact with the MFc member. Pebbles are frequently found along scoured bedding planes, mixed with clay intraclasts. Pebbles are largely polycrystalline and vein quartz, with some jasper, chert and blue quartz.

The sand-sized fraction is typically better sorted and finer grained than that of the MFc member. Some units are very well-sorted, making it impossible to detect cross-bedding. Roundness varies from subangular to near-spherical. Large sub-spherical grains occur disseminated along bedding planes and, less commonly, in thin lenses. Sand grains are largely composed of monocrystalline quartz, much of it with undulose extinction; micro- and polycrystalline grains are also present.

Clay intraclasts are mostly concentrated along bedding planes, with smaller ones being found along cross-bedding planes. They range in size up to 5 x 5 x 2 cm, but most are around 3 x 3 x 1 cm. The soft, white intraclasts consist of a kaolinite, illite, and quartz silt mixture. In places, they are hematized to red, purple or gray. Layers with clay intraclasts form from 1 percent to 30 percent of the rock; the percentage varies up-section and the variation is mappable on a regional scale. Clay intraclast layers contain between 5 and 80 percent clay intraclasts in a matrix of sand containing some granules or pebbles.

Interstitial clay is less common in the MFd member than in any other unit of the Athabasca Group, except possibly the Tuma Lake Formation. Clay content ranges from about 0.5 to 25 percent, with an average of about 2.5 percent. Clays are almost always kaolinite-illite mixtures in varying proportions. Clay grains as pseudomorphs of detrital grains are present, but less common than in the MFc member.

The major cements are silica, as syntaxial overgrowths and hematite, the latter being less common than in the rest of the Manitou Falls Formation. Silica overgrowths, resulting in lenticular silicified zones extending for considerable distances, constitute up to 50 percent of the rock.

Tourmaline and zircon occur in trace amounts; tourmaline commonly shows overgrowths. A partial section of the basal MFd member at Pine Channel (NTS area 740) is illustrated in Figure 13.

Lazenby Lake Formation

Definition, Distribution, and Thickness:

The Lazenby Lake Formation (Ramaekers, 1980a) is a pebbly quartz arenite. The type exposure is a large outcrop on the west bank of the MacFarlane River in NTS area 74G-13 (UTM coordinates 6499000 m N., 322500 m E.). A complete section through the Lazenby Lake Formation is present in the parastratotype, Canadian Southern Petroleum borehole 10-1, between 287.7 and 406.6 m.

The Lazenby Lake Formation occurs only in the Mirror and Jackfish Sub-basins (Figure 14) and is well developed over the Patterson High (Figure 4). Outcrops have been found only in the south-central area of the Athabasca Basin, but the unit likely subcrops below Pleistocene glacial and lacustrine deposits in Alberta.

The Lazenby Lake Formation overlies the Manitou Falls (d) member directly, except where separated from it by sandstones lacking clay intraclasts and pebbles, i.e. the (c) member of the Manitou Falls Formation (Figure 6, Sections 1-4, 7). The lower contact is disconformable. The sudden appearance of unmetamorphosed sandstone pebbles lithologically similar to the MFc or MFd members, along with the usual metaquartzite and vein quartz pebbles, suggests that some of the underlying Manitou Falls sandstones were indurated, eroded and incorporated at the time of the Lazenby Lake marine transgression. The upper contact of the Lazenby Lake Formation is always gradational with the Wolverine Point Formation and is arbitrarily placed at the point where pebbles no longer occur in the section.

The Lazenby Lake Formation thickens to the south and west to a maximum of about 120 m (Figure 14). Pebble sizes decrease to the north and east such that the formation is not recognizable in the Gulf Rumpel Lake borehole. A 30 m thick section of pebble-free and clay intraclast-free sandstones below the Wolverine Point Formation is probably the lateral equivalent of the Lazenby Lake Formation; these beds are lithologically indistinguishable from the MFc member and, therefore, are included with the Manitou Falls Formation.

Lithology:

The Lazenby Lake Formation is a medium to very coarse, pebbly quartz arenite. Sorting is moderate to poor. Pebbles (4 - 30 mm) are sparsely disseminated along bedding planes and may form thin (3 cm thick) conglomerates. Pebble size increases to the southwest (Map 3). Pebbles include unmetamorphosed sandstones, typically hematized, that are lithologically similar to those of the c and d members of the Manitou Falls Formation. Most pebbles are of polycrystalline and vein quartz. Blue quartz pebbles are probably more common than elsewhere in the Athabasca Basin, except for the Manitou Falls (a) strata. The sand-sized fraction is composed largely of monocrystalline quartz with undulose extinction, but poly- and microcrystalline grains are also present.

Clay intraclasts are present but sparsely distributed. Siltstone layers are present in few places. The amount of interstitial clay varies from 2 to 30 percent and averages around 7 percent; kaolinite and illite in varying proportions are the dominant clays.

Silica, as syntaxial overgrowths, and hematite are the dominant cements. Hematite constitutes roughly 0.2 to 1 percent of the rock and occurs predominantly as red stain along bedding and cross-bedding planes and as Liesegang bands. Tourmaline and zircon are present in trace amounts; tourmaline commonly shows overgrowths.

Wolverine Point Formation

The Wolverine Point Formation (Ramaekers, 1979a, 1980a) consists of interbedded sandstones, siltstones, mudstones and shales; all are devoid of granules or pebbles. The type section (Ramaekers, 1979a) is a shore cliff exposure at Wolverine Point in NTS mapsheet area 74N-1 on the south shore of Lake Athabasca, 2 km west of the mouth of the Archibald River. As this section comprises only the sandy facies of the upper Wolverine Point member, a parastratotype is designated here that provides a complete section through the Wolverine Point Formation, namely Canadian Southern Petroleum borehole 2-1 (NTS mapsheet 74K-13), from 141.7 m to 608.7 m. The first exposures of the 'Athabasca sandstone' ever described (McConnell, 1893) were

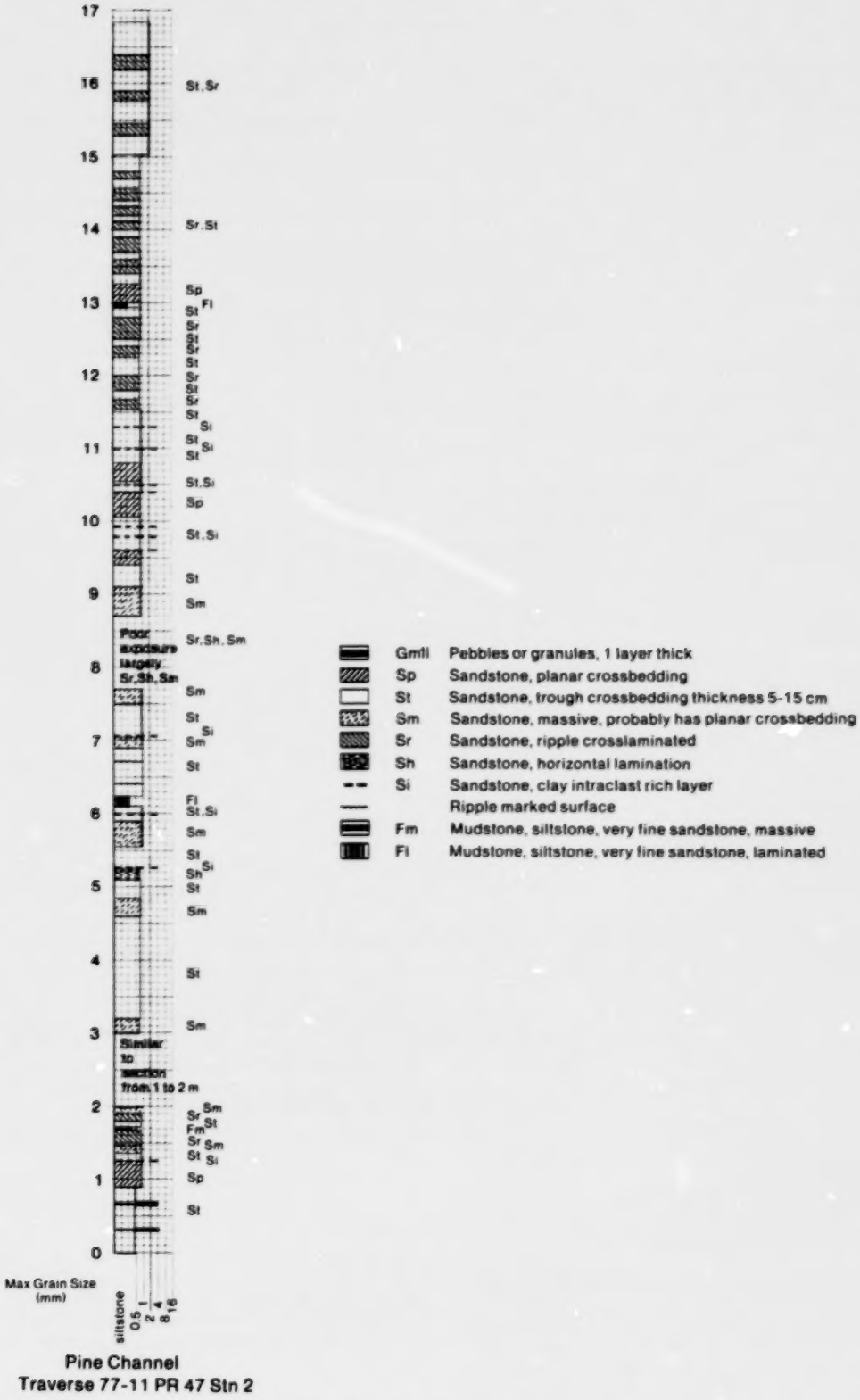

Figure 13 – Representative partial section through the basal MFd Member.

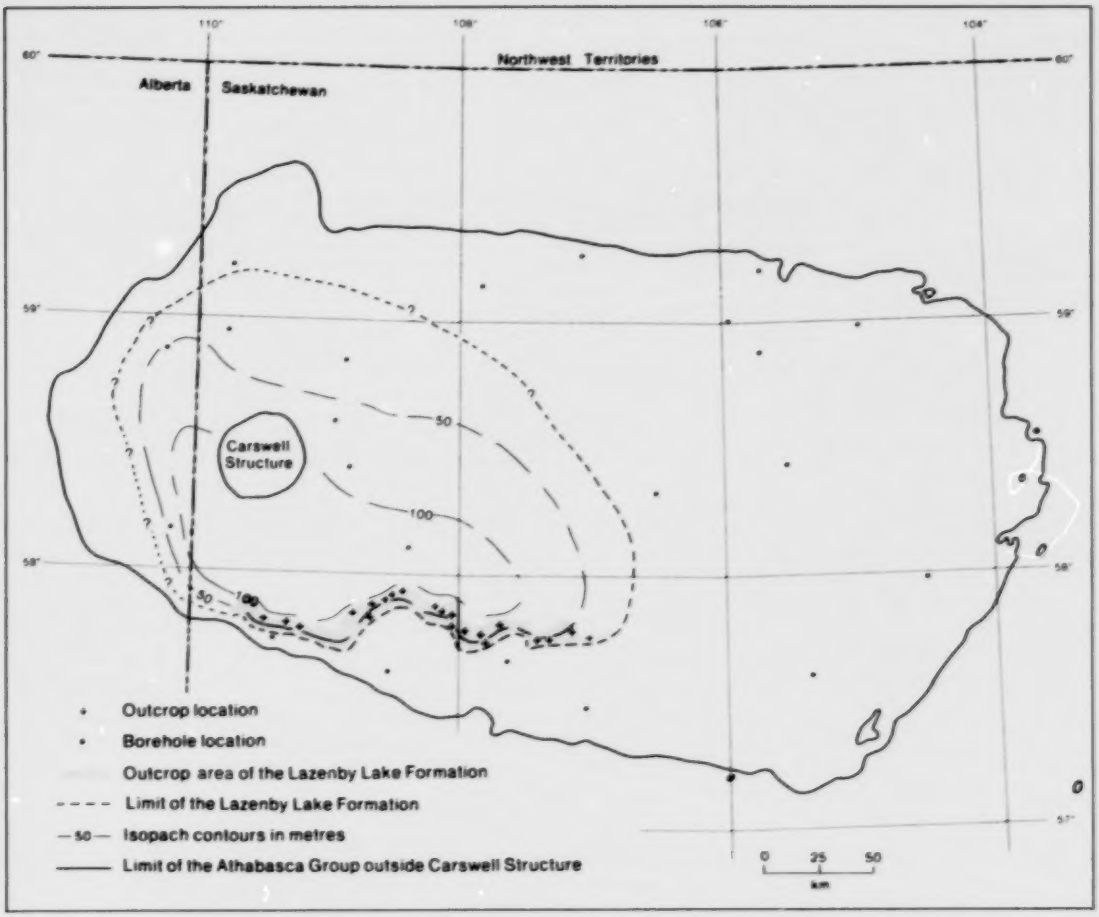

Figure 14 – Isopach Map of the Lazenby Lake Formation.

probably of the Wolverine Point Formation and/or the overlying Locker Lake Formation.

The Wolverine Point Formation is divided informally here into a lower member consisting of thin silt and mudstones interbedded with sandstones, and an upper member containing more and thicker fine-grained beds.

Lower (Clay-poor) Member of the Wolverine Point Formation (WPa)

Definition, Distribution and Thickness:

The WPa member is defined informally here as consisting of pebble-free, medium- to very coarse-grained, well- to poorly sorted quartz arenites which can be found interbedded regularly with siltstones from 5 cm to 20 cm thick. The siltstones are similar in thickness, but show much greater continuity than those of the Manitou Falls Formation.

The parastratotype includes a complete section through the WPa member from 272.8 to 608.7 m in Canadian Southern Petroleum borehole 2-1. The WPa member occurs throughout the Mirror and Jackfish Sub-basins, except at their edges, may overlap the western edge of the Cree Sub-basin, and is present in the intervening highs (Figure 15). The unit is more friable than the underlying formations and outcrops are few; areas underlain by the WPa member form topographic lows (Figure 6, Sections 1-5, 7).

The lower contact of the WPa member is with the Lazenby Lake Formation, wherever it occurs, and with the (c) or (d) member of the Manitou Falls Formation where the WPa member overlaps the Lazenby Lake Formation. The lower contact is probably gradational throughout, as the upper beds of the Manitou Falls Formation are likely to be the lateral sandy equivalents of the Lazenby Lake Formation.

The upper contact of the WPa member is transitional to a more silt and clay-rich unit (the WPb member) and is

arbitrarily placed at the first occurrence of the thick (30 cm) siltstone or mudstone beds of the WPa member. The WPa underlies the WPb member at all points. This definition provides a mappable boundary, but one that is not at precisely the same stratigaphic datum everywhere. The WPa member thickens to the north and west to a maximum of about 300 m in the northern Jackfish Sub-basin (Figure 15).

Lithology:

About 95 percent of the WPa member consists of medium- to very coarse-grained quartz arenite. Roundness varies from subangular to well-rounded and sorting is moderate to good. Pebble and granule-sized material is quite rare, although a few very thin lenses occur. Pebbles and granules are of polycrystalline and vein quartz. The sand-sized fraction is composed of monocrystalline quartz, much of it with undulose extinction.

Clay intraclasts in the sandstones are moderately common but irregularly distributed, mostly occurring stratigraphically close to the siltstone and mudstone layers. Intraclasts up to 10 x 10 x 1 cm are present, but small ellipsoidal clasts 0.5 to 1 cm across are more common. The larger intraclasts are much flatter and thinner on average than those of the Manitou Falls Formation. They are hard due to induration by hematite and/or silica. Interstitial clay in the WPa sandstones varies from 2 to 60 percent and averages around 7 percent. Clays are typically an illite-kaolinite mixture, richer in illite than the Manitou Falls Formation.

The dominant cements are silica (as syntaxial overgrowths) and iron oxides. The latter, in the form of hematite, is much more common than in the underlying Manitou Falls and Lazenby Lake Formations and typically constitutes from 0.1 to 4 percent of the rock. Iron oxides occur predominantly as red, purple or gray stains in the oxidized portions of the rock and as green stain in the reduced areas. Hematite stains are irregularly distributed through the rock; they occur as layers up to 3 m thick, irregular patches, bands along bedding or cross-bedding, red spots with white cores, and Liesegang bands. White reduced spots up to 2 cm in diameter can be seen in hematized zones; in some

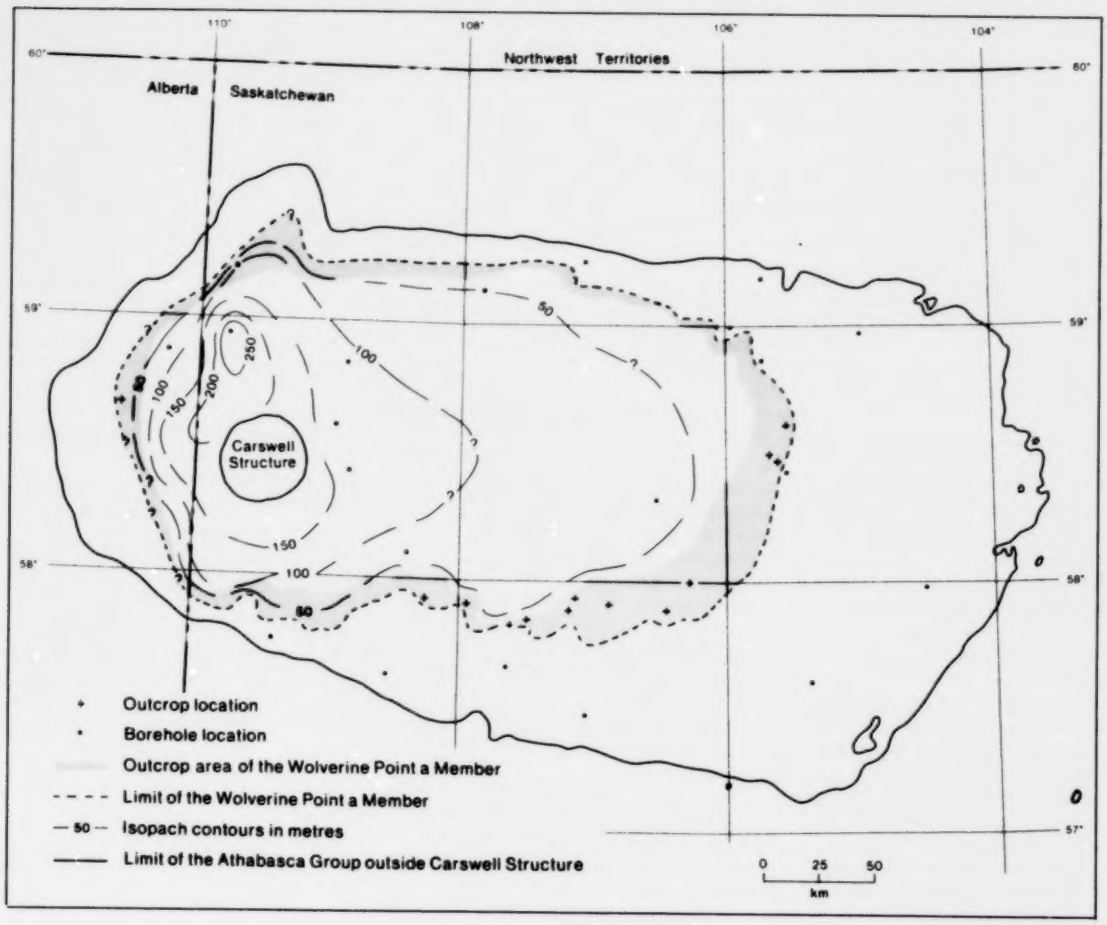

Figure 15 – Isopach map of the Wolverine Point (a) Member.

cases they are centered on pyrite crystals. Zones of red spots and Liesegang bands usually separate strongly hematized zones from rock which has been leached white. Both hematized and leached zones occur along fractures. Siderite occurs rarely as patchy cement. Tourmaline and zircon are present in trace amounts; tourmaline commonly shows overgrowths.

The fine-grained strata of the WPa member are typically between 5 and 20 cm thick and consist of laminated or massive silty mudstones, siltstones, sandy siltstones or very fine-grained sandstones. They are strongly hematized to red or purple. Some are very hard, apparently silicified, and rusty brown. Clear mica flakes up to 3 mm in diameter are commonly present and lie parallel to the bedding.

Upper (Clay-rich) Member of the Wolverine Point Formation (WPb)

Definition, Distribution and Thickness:

The WPb member is defined informally here as consisting of thin phosphorites and four interbedded clastic lithofacies: a) medium- to coarse-grained quartz arenites with a moderate interstitial clay content (i.e. similar to the sandstones of the WPa member); b) friable, medium to very coarse quartz arenites with a high interstitial clay content and a high porosity; c) fine-grained clastics (very fine sandstones to mudstones) in units from 1 cm to 50 m thick; and d) fine-grained, water deposited altered tuffs. Zones with depositional and diagenetically emplaced apatites form thin phosphorites within all clastic lithofacies.

The type exposure of the Wolverine Point Formation mostly shows the clay-poor sandy lithofacies of the WPb member. A complete section through the unit is present in the parastratotype, Canadian Southern Petroleum core 2-1 from 141.7 to 272.8 m.

The fine-grained units are not evenly distributed through the sandy lithofacies. In the Mirror Sub-basin (Gulf Rumpel Lake borehole), these units are concentrated near the top and, to a lesser extent, the bottom of the WPb member; to the northwest their distribution seems more uniform. Lack of boreholes precludes correlation of individual beds at present. The total amount of fine-grained material increases to the north and west.

The WPb member is present in the Jackfish and Mirror Sub-basins and on the intervening Patterson and Dufferin Highs (Figure 16). The sediments of this unit are very friable and weather recessively (Figure 6, Sections 1-5, 7), forming a series of large lakes around the Athabasca Basin: Lake Athabasca, and Helmer, Richards, Engler, Thomson, Engemann, Mayson, Dunning and Taggart Lakes. Outcrops occur only in canyons, along shorecliffs, and along the lower reaches of escarpments where the resistant overlying Locker Lake Formation forms a protective cover. The more resistant units show abundant jointing. Glacial plucking has resulted in the massive development of flagstone beaches that mark present and Pleistocene lakes underlain by the WPb member.

The lower boundary of the WPb member is the gradational and conformable transition from the WPa member and is arbitrarily placed at the first occurrence of thick (30 cm) siltstone or mudstone beds. No exposure of this contact is known.

The upper contact of the WPb member is marked by the pebbly sandstones of the Locker Lake Formation and is arbitrarily placed at the first occurrence of pebbles more than 8 mm in diameter. In boreholes, maximum grain size increases rather irregularly around this contact, however, pebbles 8 mm in size are generally found within 25 m of the first appearance of material greater than granule size at the top of the Wolverine Point Formation. In outcrop, where exposure at a particular stratigraphic level is much more extensive, the transition from WPb to Locker Lake Formation seems much sharper. The presence of unmetamorphosed sandstone pebbles in the Locker Lake Formation suggests that the contact is disconformable. Dramatic thinning of the Wolverine Point Formation occurs in the Chevron 77-4 borehole in Alberta. This indicates either erosion or a considerable period of non-deposition in the area during or after late Wolverine Point time and before deposition of the Locker Lake Formation.

The WPb strata have an average thickness of between 100 and 150 m and reach their maximum of about 250 m in the Mirror Sub-basin (Figure 16). This greater thickness is due entirely to an increase in the sandy lithofacies. The mudstone and siltstone lithofacies increases in proportionate and absolute thickness to the west and north (Figure 17).

Lithology:

Three main interbedded primary lithofacies are present in the WPb member: a relatively clay-poor medium to coarse sandstone; a very porous clay-rich medium to very coarse sandstone; and a fine-grained facies composed of shales, and mudstones to fine sandstones. Tuffs are relatively minor whereas phosphorites form a largely diagenetic lithofacies that may be found in all other facies of the WPb member.

The clay-poor sandstones are similar to those of the dominant lithofacies of the WPa member, a medium- to coarse-grained quartz arenite with moderate to good roundness and sorting, predominantly silica cement and about 7 percent interstitial clays. The main difference in the WPb member is that the clays are dominantly illite. A more detailed description is given in the section on the WPa member.

The porous, clay-rich lithofacies is unique to the Wolverine Point (b) member. Although sandstones of the Fair Point Formation have similar porosity values and appearance, and contain interstitial clay, they are pebbly. The clay-rich sandstones are medium- to very coarse-grained quartz arenites, subangular to subrounded, and moderately to well-sorted. Grains are largely monocrystalline quartz, much of it with undulose extinction.

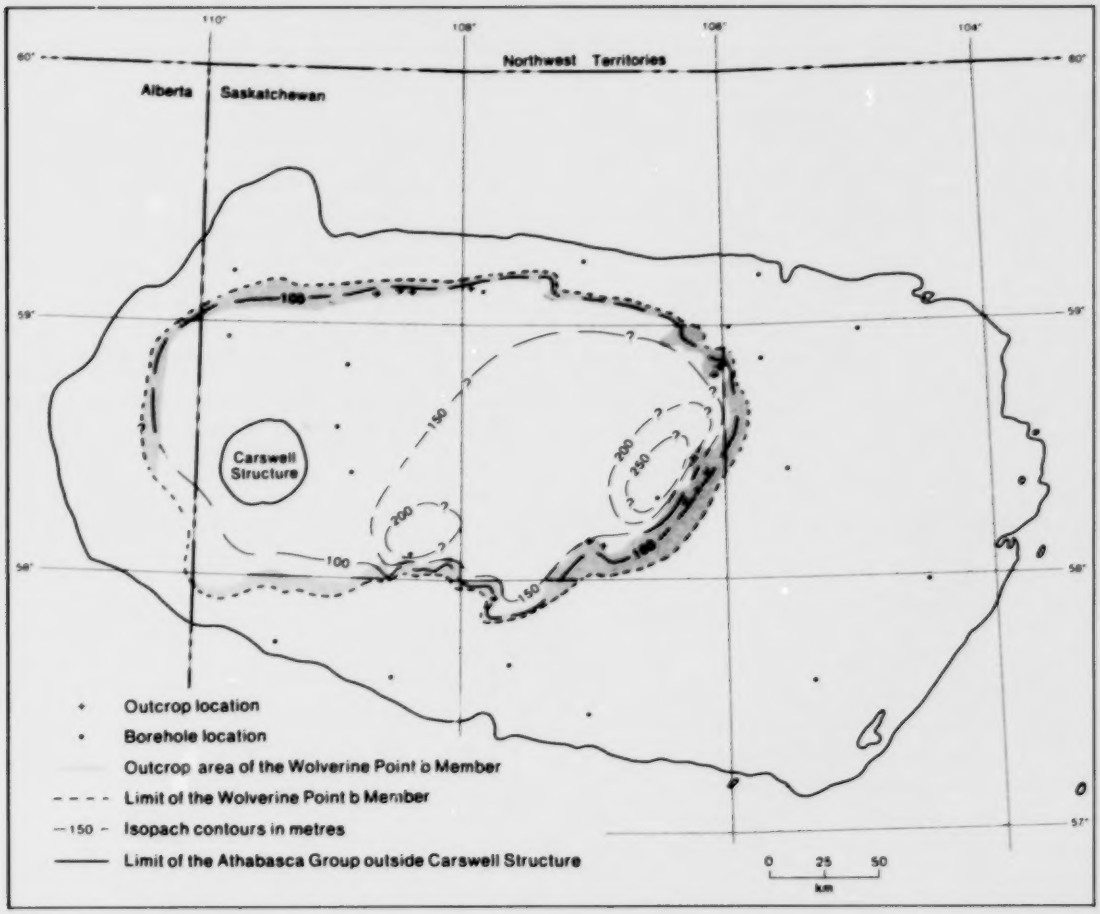

Figure 16 – Isopach Map of the Wolverine Point (b) Member.

The clay-rich sandstones are characterized by the presence of large, intergranular pores that are either void, partially filled with anhedral, doubly terminated quartz, or filled by clay pellets the size of the surrounding detrital quartz grains. In places, quartz grains full of inclusions are present, possibly quartz pseudomorphs of clays or feldspar. The inclusion-rich quartz grains and the clay grains are distributed through the rock in the same pattern as the pores elsewhere in the lithofacies. In contrast to the variable thicknesses (1 cm to 50 cm) of beds in the fine-grained lithofacies, the clay-rich sandstones form beds from 1 to 12 m thick, with an average of about 7 m thick. Despite the high clay content, permeability is high.

Clay intraclasts are common. They frequently occur in layers, particularly just above the fine-grained beds. The intraclast-rich layers are generally more diffuse than those of the Manitou Falls Formation and contain a much greater proportion of sandy matrix. Large intraclasts are common and generally flatter than those of the Manitou Falls Formation. Biotite is reasonably common, and is found in all stages of alteration, forming pale green illite nodules as an end product in reduced zones. Thin 1 - 2 mm thick clay drapes are common and form parting surfaces, particularly above ripple marked surfaces. Muscovite flakes, 1 - 2 mm in size, are common and lie parallel to the bedding. Interstitial clay content in the clay-rich sandstones varies from 2 to 60 percent and averages about 12 percent.

Silica, hematite, apatites and, to a lesser extent, carbonates (usually calcite, but also dolomite or siderite) are the most common cements. Dolomite and siderite also occur in fractures. Silica and hematite cements occur much as in the WPa member, but massive euhedral specular hematite can constitute up to 35 percent of the rock. In the apatite and carbonate cemented zones, and in some clay-rich zones, fresh feldspars - microcline and twinned plagioclase - are found. Tourmaline and zircon are present in trace amounts; tourmaline commonly shows overgrowths.

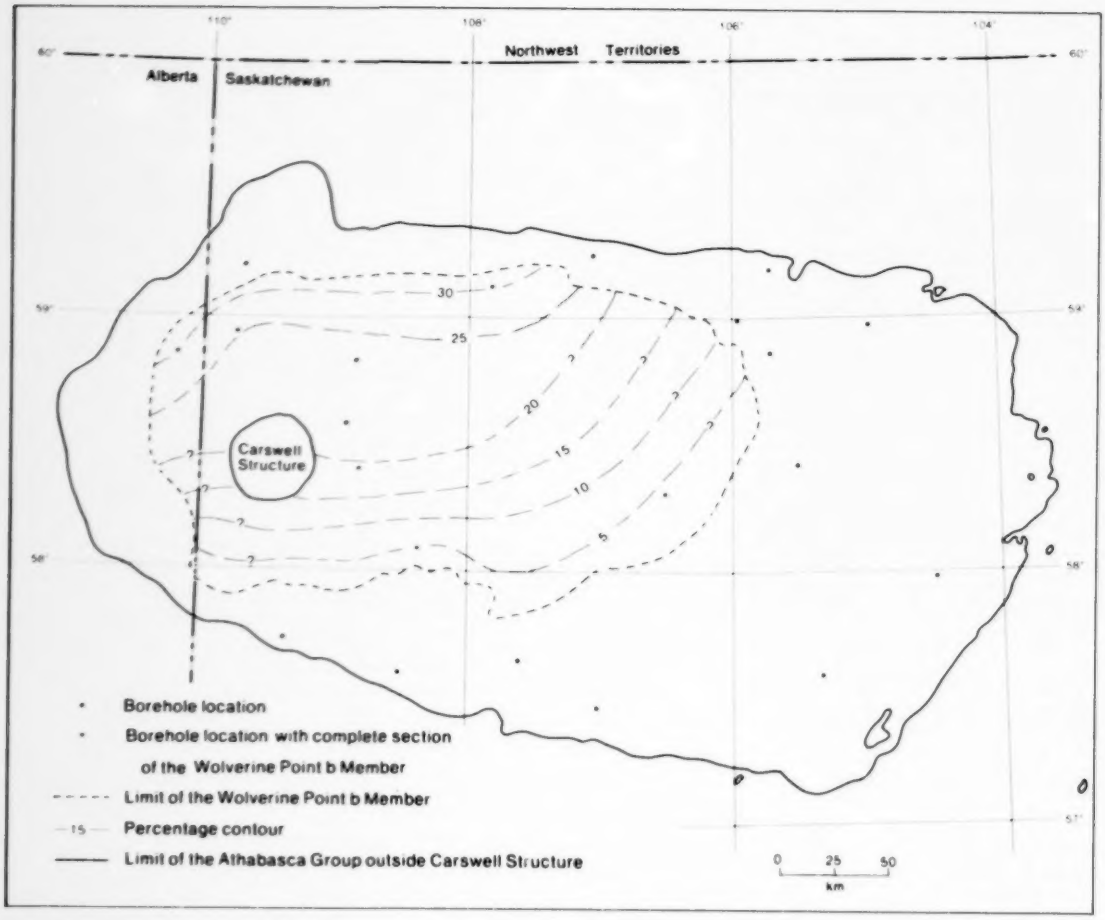

Figure 17 – Percentage of fine-grained lithofacies in the WPb Member.

The fine-grained lithofacies typically consists of lenses of claystones, siltstones and very fine sandstones, ranging in thickness from 1 cm to 50 cm. Beds are thicker towards the north and west of the Athabasca Basin. Thicker units may contain thin (1 to 5 cm) ripple-marked beds of coarser material.

The silt-sized and fine sandstone fraction consists of angular monocrystalline quartz grains set in a clay matrix. Stylolitic seams are common with and without well crystallized illite or authigenic muscovite flakes along them. In calcite cemented zones, as in clay indurated siltstones, microcline and twinned plagioclase may be found. Carbonate grains, possibly pseudomorphs of feldspar, are present also. Silica and hematite cements occur much as in the clay-rich sandstone lithofacies.

Tuffaceous zones are probably fairly common in the Wolverine Point (b) member; to recognize them is difficult as the tuffs have all been replaced by authigenic minerals, largely clays, silica and hematite. Trace element analysis shows anomalously high values in most heavy metals, but this is not a valid field criterion. Beds of small, flat, ovoid pebbles, typically 2 x 10 x 10 mm are common in the WPb member. Unlike the large intraclasts of the Manitou Falls Formation and most of the large clay intraclasts of the Wolverine Point Formation, the pebbles are too hard to scratch with a fingernail. These small intraclasts consist of silicified, hematized clays. In apatite indurated zones, apatite pseudomorphs of these intraclasts replace what were originally volcanic glass shards, pumice, or a mixture of replaced 'spicules' and detrital quartz. Monocrystalline, deeply embayed quartz, possibly of volcanic origin, is found in the same strata.

In a few places, thin-sections of a fine-grained dense rock with a conchoidal fracture show vague spicule-like forms that are set in a fine-grained groundmass. These are similar to the spicular shapes found in the better preserved tuffaceous intraclasts of undoubted volcanic origin. Thus it is reasonable to interpret this rock as an altered bedded tuff.

Phosphatic beds have been encountered in nearly all boreholes penetrating the WPb member. The beds typi-

cally consist of zones up to 6 m thick with P_2O_5 analyses of several percent along with thin (30 cm) zones with up to 20 percent P_2O_5. The phosphates consist largely of fluor-apatite and carbonate fluor-apatite, although other phosphatic minerals are probably present. Apatite occurs in several forms: as distinct grains; collophane deposited in concentric layers around sand grains; euhedral cement in crystals radiating from quartz grains; euhedral cement randomly oriented in pores; and vein fillings in fracture zones. The apatite crystals are often zoned, with hematite coatings separating growth stages. The oldest and most radioactive generations of apatite (collophane and radiating euhedral crystals) are generally fluor-apatite. Vugs are often lined with carbonate fluor-apatite. The outer zones of the euhedral apatite crystals generally have a lower natural uranium content, as witnessed by a lower natural fission track density, suggesting a decrease in uranium content of pore waters with time. The zones cemented by collophane or radiating euhedral apatite crystals are virtually the only places in the Athabasca Basin where fresh detrital feldspars are preserved, suggesting that this form of cement was introduced very early.

Locker Lake Formation

Definition, Distribution, and Thickness:

The Locker Lake Formation (Ramaekers, 1979a, 1980a) consists of poorly sorted, medium to very coarse, pebbly quartz arenites, interbedded with minor amounts of fine-grained sandstones, siltstones and a few thin mudstones. The type section (Ramaekers, 1979a) is a large outcrop 8 km west of Locker Lake (NTS mapsheet 74J-9; UTM coordinates 436800 m E., 6500400 m N.). As no outcrop of the Locker Lake Formation provides a complete section, a parastratotype is here designated: Canadian Southern Petroleum borehole 8-1, from 98.5 m to 292.6 m (NTS mapsheet 74K-7; UTM coordinates 627600 m E., 6478800 m N.). This core contains a complete section through the Locker Lake Formation and enough of the overlying and underlying strata to study contact relationships.

The Locker Lake Formation is preserved in the Jackfish and Mirror Sub-basins and on the intervening Patterson High (Figure 18). It is a resistant rock unit that typically

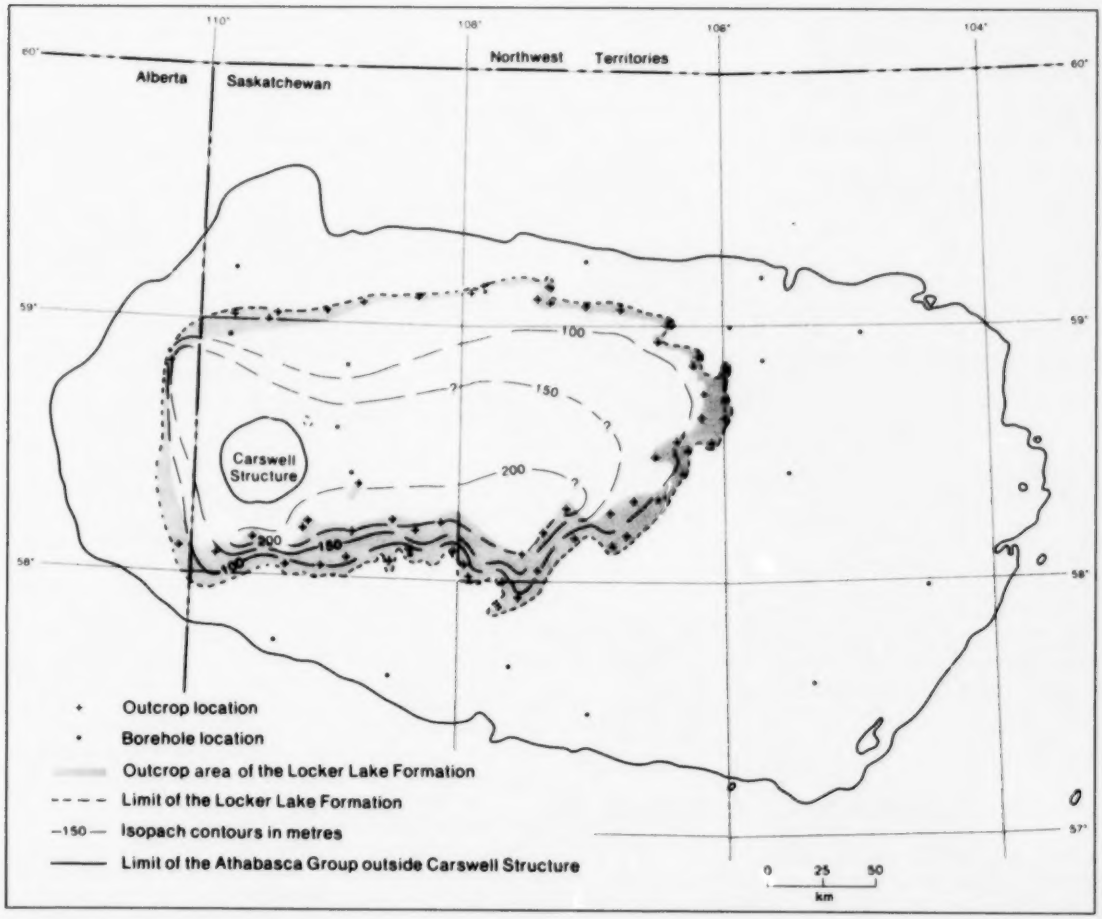

Figure 18 – Isopach Map of the Locker Lake Formation.

forms escarpments along the northern and eastern side of its range (where it faces the direction of glacial movement). Most of the waterfalls in the Athabasca Basin are due to resistant ledges of the Locker Lake Formation. Exposures of the Locker Lake Formation typically show massive sandstones with relatively few joints. At the surface, the sandstones are quite friable.

The type exposures of the Athabasca sandstones (McConnell, 1893) probably included outcrops of the Locker Lake Formation. The lower contact of the Locker Lake Formation is always with the Wolverine Point (b) strata and is defined as the level of first occurrence of pebbles greater than 8 mm in diameter. This generally occurs within short stratigraphic distance of the first occurrence of small pebbles in the upper WPb member. The contact locally shows pronounced unconformities and the presence of unmetamorphosed sandstone pebbles suggests that it is disconformable over most of the southern and eastern parts of its range. In the northern and western part of the Athabasca Basin the contact may be conformable. The upper contact is transitional to the finer grained deposits of the Otherside Formation, and is arbitrarily placed at the stratigraphically highest occurrence of pebbles at least 8 mm in diameter. The Locker Lake Formation thickens to the south to a maximum of about 200 m (Figure 18).

Lithology:

The Locker Lake Formation consists of two main lithofacies: a coarse, pebbly quartz arenite; and interbedded, fine-grained sandstones and siltstones from 1 to 20 cm thick.

The pebbly lithofacies consists of a moderately to poorly sorted, subangular to subrounded, pebbly quartz arenite. Pebbles are up to 50 mm in diameter (Map 3), and are largely composed of polycrystalline and vein quartz, metaquartzites containing pyrite, microcrystalline quartz, and unmetamorphosed sandstone pebbles. Pebbles are disseminated along bedding planes and rarely form thin conglomerates. Clay intraclasts are very rare or absent. Interstitial clay content varies from 0.1 to 30 percent and averages around 3 percent; the clays are mainly illite and kaolinite.

Silica and hematite are the dominant cements; silica largely in the form of syntaxial overgrowths and hematite as red stain uniformly saturating the rock, bands parallel to bedding and cross-bedding, and Liesegang rings. Hematite comprises from 0.2 to 6 percent of the rock and averages around 0.7 percent. It is more uniformly distributed through the Locker Lake Formation than through other sandstones of the Athabasca Group and, as a result, unweathered Locker Lake sandstones are typically brick red.

Although they form resistant ridges, Locker Lake sandstones are friable in outcrop, which suggests that some of the cement or matrix is groundwater soluble. Thus their prominent topographic expression must be due to resistance to the physical processes of erosion dominant during glaciation.

The report of gypsum in the Athabasca sandstones (Fahrig *et. al.*, 1978) refers to joint fillings in sandstones of the Locker Lake Formation at a depth of 823 feet in the Canadian Southern Petroleum borehole 5-1 (NTS 74K). The minerals in this joint are nacrite and dickite (MRD identifications), not gypsum.

Otherside Formation

Definition, Distribution, and Thickness:

The Otherside Formation (Ramaekers, 1979a, 1980a) consists of moderately to very well-sorted, subangular to subrounded, fine- to coarse-grained quartz arenites interbedded with siltstones. The type section (Ramaekers, 1979a) is about 2 km west of the southern part of Livingstone Lake (NTS mapsheet 74J-11; UTM coordinates 362000 m E., 6496300 m N.). An outcrop in NTS mapsheet 74K-10 (UTM coordinates 633900 m E, 6506900 m N.) was designated as parastratotype. Canadian Southern Petroleum borehole 5-1, from 0-182.9 m (NTS mapsheet 74K-10; UTM coordinates 618400 m E., 6496200 m N.) has also been designated as a parastratotype as it is the longest available section through the unit.

The Otherside Formation extends through the west-central to central Athabasca Basin (Figure 19) and is exposed intermittently over much of this area. Exposures constitute about 10 percent of surface area in the east and decrease to virtually nil along the western edge of the area due to increasing cover by glacial deposits.

The lower contact of the Otherside Formation is a gradual transition from the pebbly Locker Lake Formation to the finer-grained and largely pebble-free sandstones of the Otherside Formation. The upper contact is the unexposed transition to the pebbly sandstones of the Tuma Lake Formation, assumed to be disconformable on the basis of stratigraphic similarities to the Manitou Falls/Lazenby Lake and the Wolverine Point/Locker Lake contacts.

The Otherside Formation reaches a thickness of about 180 m in the Canadian Southern Petroleum borehole 5-1, where it has an erosional upper limit. A complete 110 m section is preserved in the Nahanni Mines NR-1 borehole at Atchison Lake (NTS mapsheet 74K-15; UTM coordinates 622200 m E., 6524500 m N., core at the drillsite).

Lithology:

Two lithofacies are prominent in the Otherside Formation: fine- to coarse-grained quartz arenites, and minor 5 cm to 3 m thick units of siltstones, interbedded very fine sandstones and siltstones, and some mudstones.

The coarse lithofacies consists of moderately to well-sorted, subangular to subrounded, fine- to coarse-grained quartz arenites. Granules are present along bedding planes and small pebbles occur in the basal part of the formation. Pebbles and granules are generally of polycrystalline or vein quartz. The sand-sized frac-

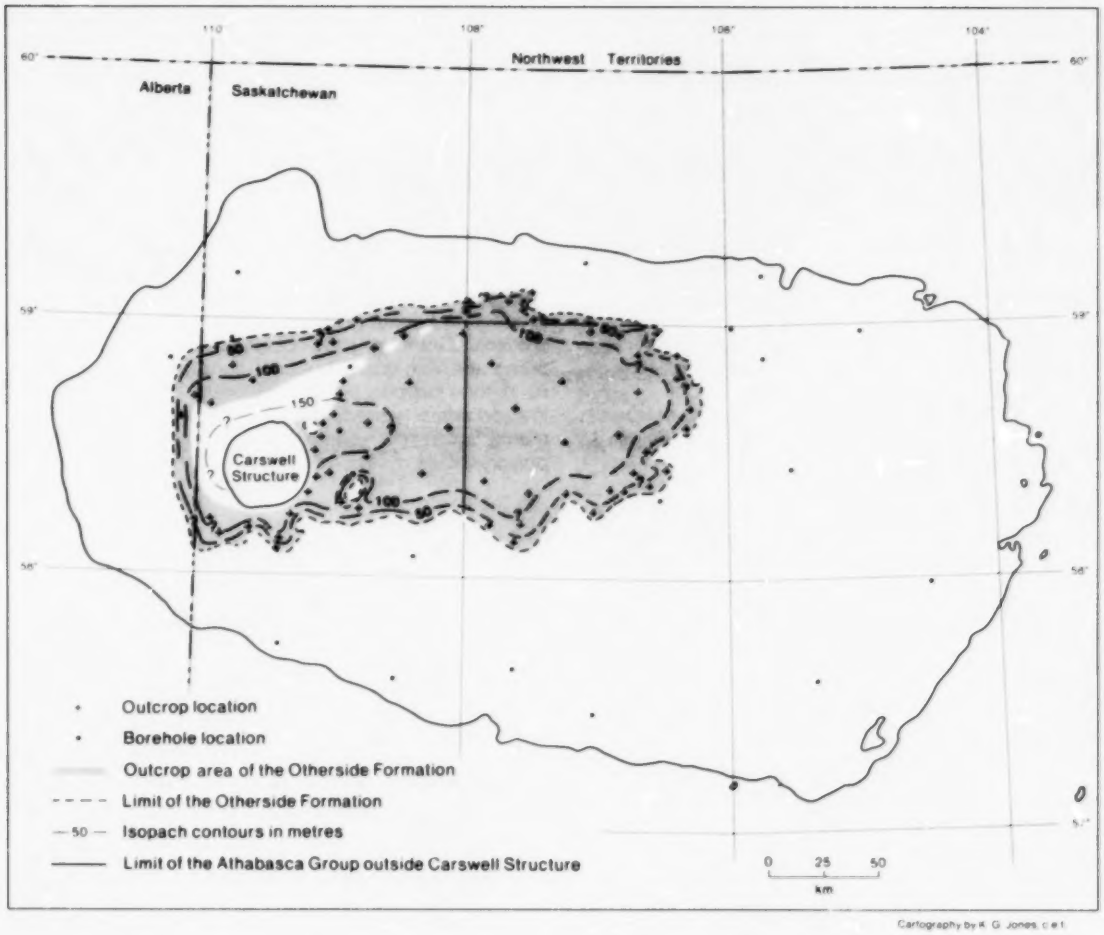

Figure 19 – Isopach Map of the Otherside Formation.

tion typically consists of monocrystalline quartz, much of it with undulose extinction.

Clay intraclasts are abundant along bedding planes, particularly near the finer-grained units. Interstitial clay varies from 1 to 40 percent and averages around 3 percent. Illite and kaolinite are the most common clays.

Silica and hematite are the dominant cements: silica as syntaxial overgrowths, and hematite as a uniform impregnation of earthy red or specular hematite, bands along bedding or cross-bedding, and Liesegang bands. Hematite content varies greatly; many outcrops are nearly devoid of hematite, whereas others are completely red, or totally impregnated with specular hematite to form a hard, dense, black rock. In the north-central part of its exposed area many outcrops of the Otherside Formation are deep red, suggesting that at least part of the hematite is stratabound. Hematite content typically varies from 0.2 to 6 percent, averaging about 0.8 percent in the hematite-poor units and about 4 percent in the hematite-rich units. Tourmaline and zircon are present in trace amounts; tourmaline commonly shows overgrowths.

The fine-grained lithofacies consists of 5 cm to 3 m thick units of thinly interbedded very fine sandstone, siltstone and a few thin mudstones. Individual sedimentation units within this assemblage are well-sorted. The silt- and sand-sized fraction consists of subangular to angular monocrystalline quartz.

Tuma Lake Formation

Definition, Description, and Thickness:

The Tuma Lake Formation (Ramaekers, 1979a) consists of pebbly quartz arenites similar to those of the Lazenby Lake and Locker Lake Formations but with a lower clay content. It forms the uppermost stratigraphic unit of the Athabasca Group outside of the Carswell Structure.

The type section is an outcrop 5 km northeast of Tuma Lake (NTS mapsheet 74K-11; UTM coordinates 609100 m E., 6504200 m N.). The parastratotype designated here is an outcrop about 100 m east of Boll Lake (NTS mapsheet 74K-11; UTM coordinates 597300 m E., 6506000 m N.).

The Tuma Lake Formation is present in the west-central area of the Athabasca Basin, along the east side of the Jackfish Sub-basin and on the Patterson High. Although its basal beds are contained in the upper 10 m of Nahanni Mines borehole NR-1 at Atchison Lake, no boreholes through the entire unit are available at present. The Tuma Lake Formation is poorly exposed in all but its northeastern range east of the Carswell River, and in scattered outcrops just outside of the Carswell Structure. The actual thickness of the Tuma Lake Formation is not known due to the lack of drillholes. Projection of regional dips from the surrounding area suggests a thickness of at least 80 m (Figure 6, Section 7; Figure 20).

The unexposed lower boundary of the Tuma Lake Formation is with the pebble-free sandstones of the Otherside Formation. This contact is assumed to be disconformable on the basis of similarities to the Manitou Falls/Lazenby Lake and the Wolverine Point/Locker Lake Formation contacts. The upper contact, only seen in cores in the tectonically disturbed Carswell Structure, appears to be a gradual transition to the siltstones and sandstones of the Douglas Formation.

Lithology:

The sandstones of the Tuma Lake Formation are medium to very coarse, subangular to very well-rounded, moderately to well-sorted, pebbly quartz arenites. Granules and pebbles are largely of polycrystalline and vein quartz but some unmetamorphosed sandstone pebbles are also present. The sand-sized fraction consists predominantly of monocrystalline quartz, much of it with undulose extinction, and some polycrystalline quartz.

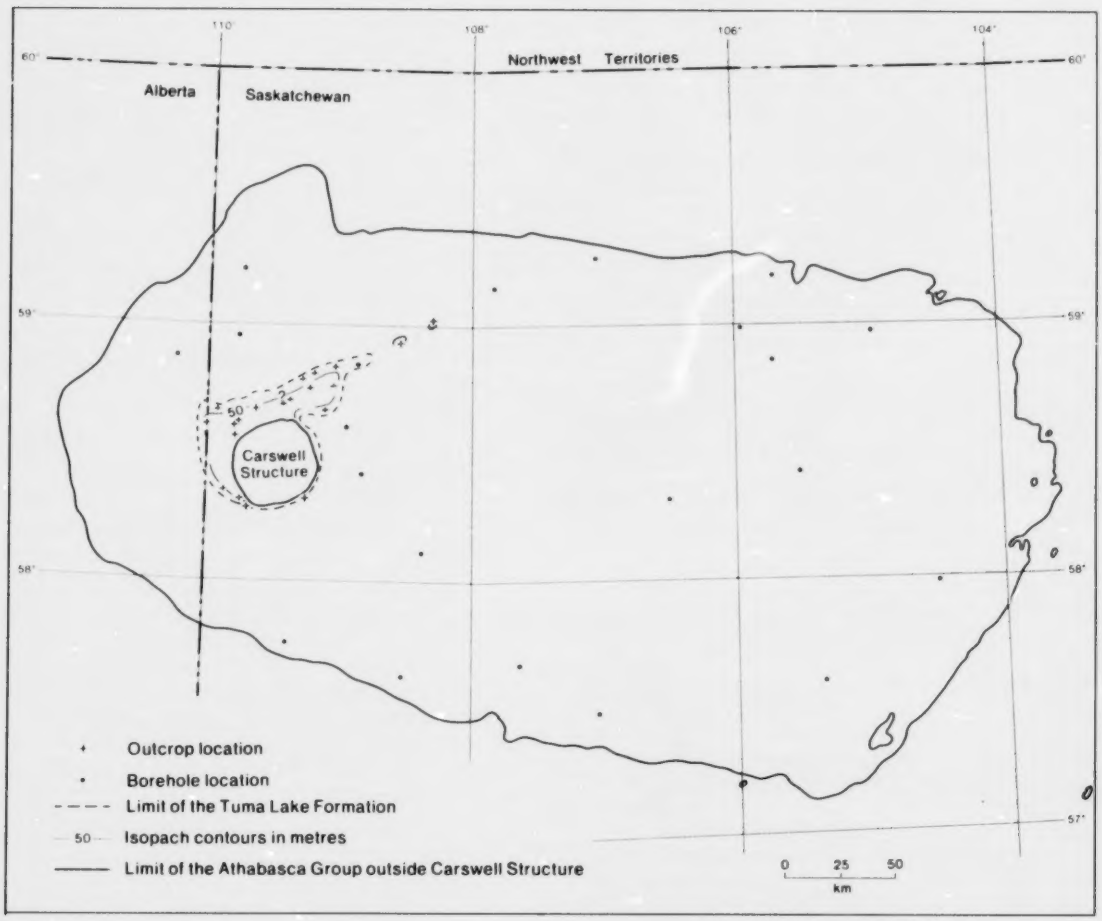

Figure 20 – Isopach Map of the Tuma Lake Formation.

Estimates of clay and cement content are probably too low because only unweathered core specimens were available for study. Clay intraclasts are virtually absent. The interstitial clay content of surface samples varies from 0.1 to 7 percent and averages around 0.5 percent.

Silica and iron oxides are the most common cements; silica is in the form of syntaxial overgrowths. Hematite is found as pervasive red staining, Liesegang rings and red spots. Limonitic Liesegang rings are very common in some outcrops. Iron oxide content varies in surface samples from 0.2 to 4.5 percent and appears bimodally distributed. It averages around 0.6 percent in light coloured rock and about 3 percent in the brown, red or gray iron oxide stained sections.

Points Lake Subgroup

The Points Lake Subgroup includes the Douglas and Carswell Formations, which are only found in the Carswell Structure in the west central part of the Athabasca Basin (Map 2). The Douglas Formation is virtually unexposed in contrast to the well exposed Carswell Formation.

Douglas Formation

Definition, Distribution, and Thickness:

The Douglas Formation (Amok, 1974), which consists of black, red and green, finely interbedded and interlaminated, very fine sandstones, siltstones, mudstones and minor coarser sandstones, is very friable and virtually unexposed. The best available type exposures, as designated here, are scattered, poorly exposed outcrops just south of the Douglas River and from 1 to 2 km west of the Semchuk Trail bridge across the Douglas River. This is in accordance with the informal description and map of the unit in Amok's publication, which did not formally define the Douglas Formation. The parastratotype is Amok Ltd.'s core CAR 181, from about 213 m to about 424 m. This core comes from a northeastern exposure area of the Douglas Formation indicated on Amok's (1974) map, and is stored by Amok Ltd. at their Cluff Lake camp. Samples of this core are available for inspection at the Saskatchewan Department of Energy and Mines Geological Subsurface Laboratory in Regina.

The base of the Douglas Formation is defined as the last pebbly sandstone unit at the top of the pebbly Tuma Lake Formation. Its upper contact is placed at the first occurrence of dolomites of the Carswell Formation. The sedimentary contacts of the Douglas Formation are not exposed, and may be difficult to identify even in core due to the abundance of faulting within the Carswell Structure.

On their maps, Fahrig (1961) and Currie (1969) showed some outcrops of siltstones and 'shales' which they included with their 'Athabasca formation'. These outcrops are placed here with the Douglas Formation. Amok (Canada) Ltd. (1974) presented a map of the Carswell Structure outlining areas where glacial and periglacial deposits were underlain by the Douglas Formation.

Assuming that the very friable Douglas Formation clastics form topographic lows due to glacial plucking, an estimate of the minimum extent of the Douglas Formation (Figure 21) can be made by extrapolating from these outcrops, and integrating this data with outcrop locations of the sandstones and dolomites.Assuming further that the radial symmetry apparent in the dolomites is also present in the Douglas Formation, and that glacial deposits may have filled topographic lows where these are immediately up-ice of the resistant carbonates, then a maximum extent of the Douglas Formation may be derived (Figure 22). This maximum estimate has been used in the maps that accompany this report and in the previous Summary Reports (e.g. Ramaekers, 1980a).

The assumption of concentric symmetry of the Douglas Formation in the Carswell Structure is much less certain than that of glacial excavation of the friable unit by Pleistocene glaciation. The Douglas clastics are less competent than the dolomites of the Carswell Formation or the relatively well-indurated sandstones of the William River Subgroup. The structural geology of the Carswell Structure is exceedingly complex, and may be unpredictable over distances as little as 50 m. Detailed maps of the Douglas Formation must come from core studies.

The Douglas Formation outcrops both within and outside the dolomites of the Carswell Structure. Previously, these exposures have been considered part of the same unit and its appearance on both sides of the dolomites ascribed to faulting and overturning along the inside of the Carswell Structure core (Harper, 1978). However, the amount of overturning is overestimated. Certainly the Carswell Formation (details below) is dipping largely and rather uniformly towards the center of the structure, with dips generally between 30° and 60°. Whether this relatively simple relationship of the dolomites extends to the less competent Douglas Formation is not known. Much of the Douglas Formation core studied by this author was not overturned. Whether the overturning, where it does occur, is due to dragging near faults, as is the case with the Carswell Formation dolomite, or is representative of parts of the inner ring of the Douglas Formation is not known. If there is no large-scale overturning present, then the possibility that two formations exist with the lithology of the Douglas Formation, one above and one below the Carswell Formation, will have to be evaluated. Such an evaluation would necessitate deep drilling through the Carswell Formation, and detailed stratigraphic analysis of the Carswell and Douglas Formations. In this report the traditional view admitting only one fine clastic unit, that below the Carswell Formation is tentatively kept.

Cores have provided stratigraphic sections into the Douglas Formation over 200 m thick. These sections cut numerous fault zones at which repetition or deletion of parts or all of the section may have occurred. Detailed stratigraphic analysis of many cores will be necessary before any reliable estimate of the thickness of the Douglas Formation is possible. The 185 m

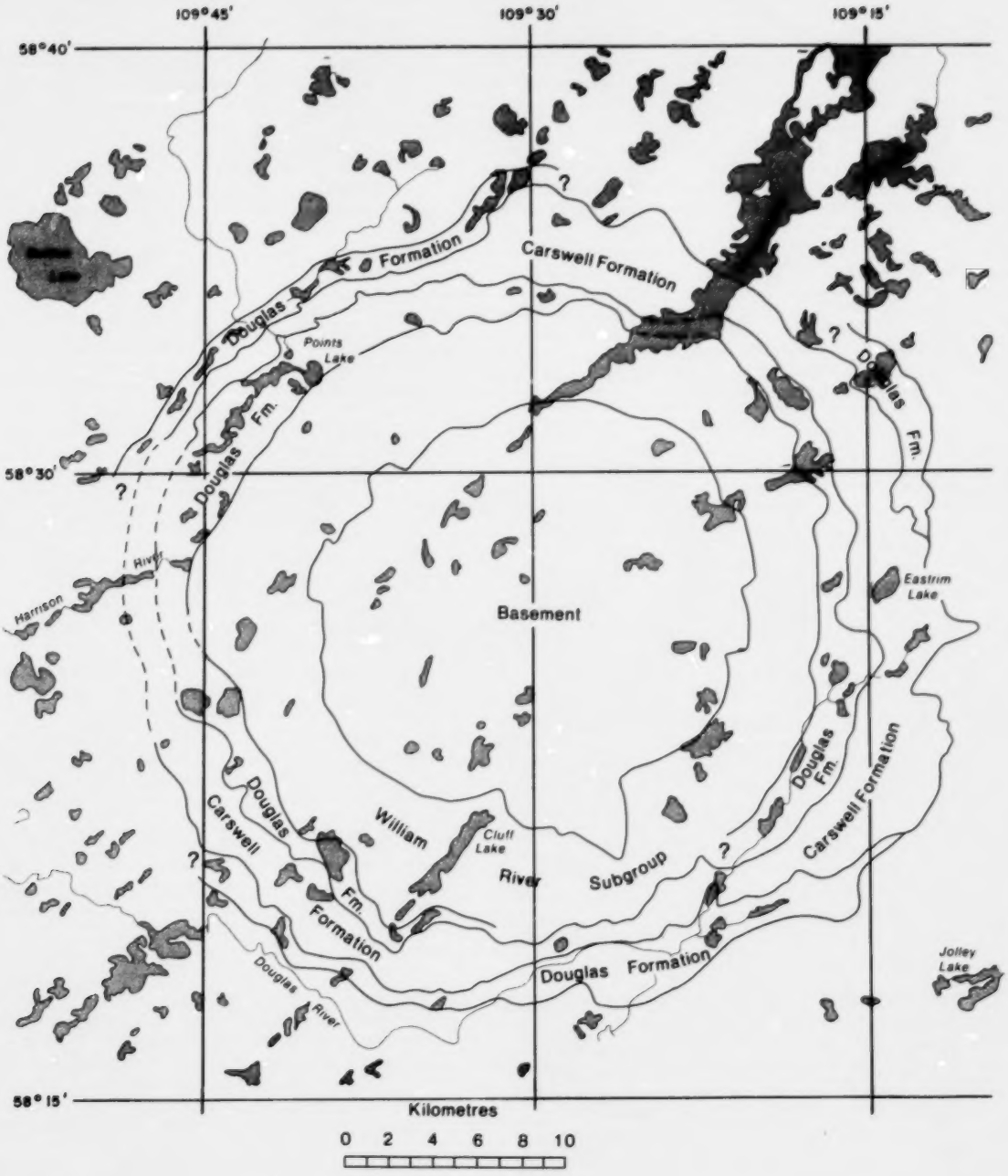

Figure 21 - Minimum extent of the Douglas Formation.

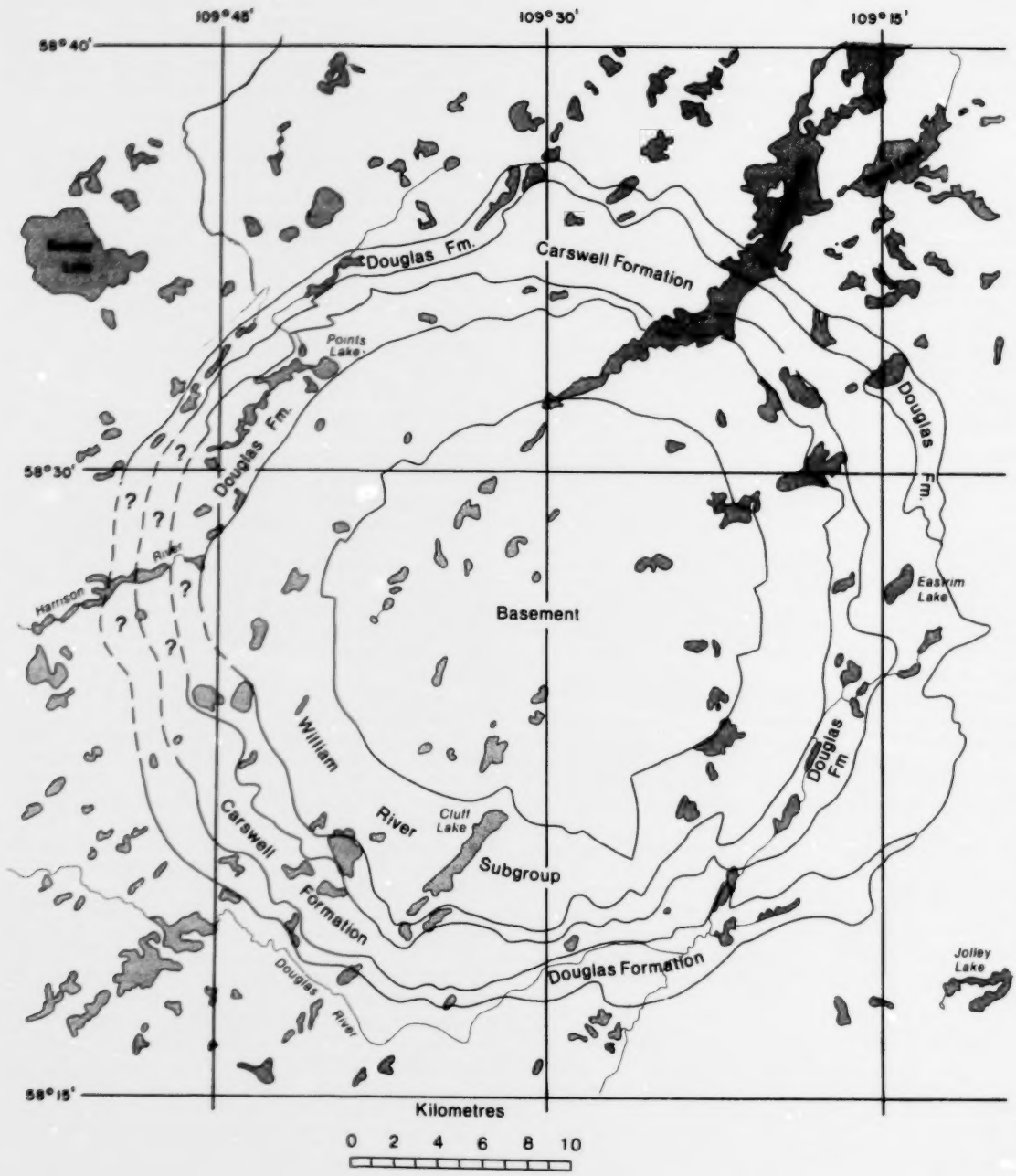

Figure 22 - Maximum extent of the Douglas Formation.

stratigraphic thickness of the Douglas Formation in the CAR 181 borehole is not overturned and the rock seems relatively undisturbed, therefore, this figure may be tentatively taken as an initial estimate of the thickness of the Douglas Formation.

Lithology:

The clastics of the Douglas Formation are typically laminated grey, graded beds of fine- to very fine-grained sandstones interlaminated with black, green and red siltstones and mudstones. Graded beds range from 0.25 to 5 cm thick. The grading is due to an upwardly decreasing thickness of sandstone laminations, resulting in a graded unit that varies from nearly pure sandstone at the base to nearly pure siltstone at the top. The basal sandstones of a graded bed generally show abundant load casting in many parts of the Douglas Formation, and form ball and pillow structures in the underlying siltstones and mudstones. Some sand-filled syneresis cracks are also present. The sand/silt ratio of the Douglas Formation varies; most beds are predominantly sandstone and show only thin siltstone laminae.

Near the top of the formation, beds of the above lithology are interbedded with limy clastics, coarse sandstones and eventually with the dolomite beds marking the base of the Carswell Formation. Whether this interbedding is due to sedimentary facies changes is not always clear; some may be due to tectonism. Towards the base of the Douglas Formation the graded siltstone/sandstone units are interbedded with increasing amounts of coarse sandstones, finally becoming the first pebbly beds marking the top of the Tuma Lake Formation. Thus, both the upper and lower contacts of the Douglas Formation appear to be gradational.

The clastics consist largely of quartz, but contain both microcline and plagioclase feldspar. Clay content ranges from 5 to about 80 percent and averages about 30 percent according to visual estimates of cores.

The typically black mudstones contain up to 0.5 percent organic carbon. Algal filaments and spherules are present in acid residues prepared from the mudstone fraction. The black mudstones are frequently altered to red or green colours, presumably due to oxidation or reduction of their pyrite content. The interbedded coarser sandstones are typically pale yellow, red or green.

Carswell Formation

The carbonates of the Athabasca Group were discovered by Blake (1956), who called them the 'Trout Lake Limestone'. He assumed them to underlie the Athabasca sandstones, although he emphasized that they could well be a 'locally deformed' part of the 'Athabasca series'.

Gussow (1957, 1959) correctly assigned these carbonates, his 'Trout Lake Dolomite member of the Athabasca formation', to their correct stratigraphic position as the youngest member of the 'Athabasca formation' (equivalent to the Athabasca Group of this report). Gussow also recognized for the first time the dolomitic nature of the carbonates, the oolites, the minor detrital quartz trapped in the dolomites, and that much of the brecciation was syndepositional rather than tectonic. In addition, he first recorded that the dolomites formed a circular structure, quoting a personal communication from K.D. Hannigan (this discovery was erroneously attributed to Fahrig (1961) by Currie (1969)).

Fahrig (1961) changed the name of the dolomites to 'Carswell Formation' from Gussow's (1959) 'Trout Lake Dolomite' and Blake's (1956) 'Trout Lake Limestone', emending its status from member to formation. This is not warranted according to Article 12, Remark (b) of the Code of Stratigraphic Nomenclature by the American Commission on Stratigraphic Nomenclature (1961), with input from the Geological Survey of Canada. However, as the name 'Carswell Formation' has become widely accepted it is retained here under Article II, Remark (b) of the Code.

Definition, Distribution, and Thickness:

The Carswell Formation (Trout Lake Limestone of Blake, 1956; Trout Lake Dolomite member of the Athabasca Formation of Gussow, 1957, 1959; Carswell Formation of Fahrig, 1961; Currie, 1969; Amok, 1974; and Harper, 1978b) is a dolomite that consists largely of algal laminates, domed algal stromatolites (termed Laterally Linked Hemispheroids by Logan *et al.*, 1964), interbedded with minor oolites, dolarenite, dololutite, peletal dolostones, thin chert lenses, and quartz sandstones near its contact with the Douglas Formation.

The Carswell Formation is exposed entirely within the Carswell Structure (Figure 22). The Carswell Formation was never formally defined, nor was a type section ever specified. The type section is defined here as a south trending section through the dolomites west of Carswell Lake, along UTM coordinate 590400 m E. from 6495600 m N. to 6492900 m N. This section is within the area where Blake (1956) first described the Trout Lake Limestone, but it avoids the much described cliffs along Carswell Lake in which disruption, due to the major northeast trending fault that forms the axis of the lake, prevents evaluation of the stratigraphy.

Spectacular exposures mark the major radial faults where the attitudes of the dolomites either vary chaotically or are dragged parallel to the fault plane. Unspectacular, less disturbed exposures are usually covered by vegetation, and dip towards the center of the structure. This outcrop pattern and the greater attention paid to the spectacular outcrops has obscured the relatively simple structural attitudes of the bulk of the Carswell Formation.

The conformable lower contact of the Carswell Formation is defined here as the base of the first prominent carbonate bed. The basal section of the Carswell Formation consists of interbedded dolomites, sandstones, and calcareous or dolomitic mudstones and siltstones. The sedimentary base of the Carswell Formation may

be difficult to identify due to the extreme tectonism within the Carswell Structure and possible confusion with fault contacts between the Carswell and Douglas Formations.

The upper boundary of the Carswell Formation is erosional, unless, as noted above, some of the black siltstones and mudstones that occur within the carbonate ring of the Carswell Structure are an overlying unit, similar lithologically, to the Douglas Formation.

Currie (1969) divided the Carswell Formation into two members:

1) a lower thinly bedded, fissile dolomite with many 'calcarenites' (more correctly called dolarenites as they consist of dolomite) and stromatolitic zones, with the highest stromatolitic unit defining its top and
2) an upper thickly bedded, massive dolomite.

As part of this study three measured sections were attempted through the Carswell Formation: one 3 km west of Carswell Lake (the type section as defined in this report); a section 2 km north of Points Lake (Figure 23); and a section south-southwest of the southern tip of Cluff Lake. The most continuous was the section near Points Lake, all of which should be in the upper, massive member of the Carswell Formation according to Currie (1969, Figure 1). Of the approximately 675 stratigraphic metres traversed, less than 20 percent could be termed massive dolomites (some of these cross-bedded) and these were generally interbedded in 50-100 cm thick beds with laminar dolomites and stromatolitic units. The traverse through the Carswell Formation south of Cluff Lake, all ostensibly in Currie's lower laminated member, showed many outcrops with massive crystalline dolomites.

Thus, it appears that Currie's division of the Carswell Formation is based on inadequate evidence and should be discarded, and that Currie's map (1969, Figure 1) extrapolates too far from his outcrop data. His diagnostic criteria for the lower member of the Carswell Formation - the lamination and stromatolitic zones - are abundant throughout the Carswell Formation. These structures are well displayed on thoroughly weathered rock, but may not be visible on fresh surfaces of the same specimen.

In view of the extensive tectonism affecting the Carswell Structure, probably resulting in considerable thrust faulting, and the possibility that, in any one section, various segments of the Carswell Formation may be repeated, removed, or placed out of their proper stratigraphic position, it is considered premature to divide the Carswell Formation into members. Nevertheless, the presence of both quiet and high energy depositional environments suggests that, with detailed mapping, greater stratigraphic definition within the Carswell Formation is possible.

The thickness of the Carswell Formation is difficult to evaluate because of the tectonic complications. The section through the formation northwest of Points Lake (Figure 23) shows a minimum formation thickness of 625 m. The greatest indication of faulting is the prominent valleys along depositional strike-separating ridges. Given that the structural dips stay relatively constant (between 53° and 43°) throughout this part of the section, there is no evidence of overturning, and this part of the section shows no repetition, the valleys may merely be zones of more friable units within an undisturbed section of the Carswell Formation. However, it is possible that the valleys mark the sites of ring faults, possibly thrust faults parallel to the bedding plane, in which case, they may or may not affect the apparent thickness of the formation. Alternatively, the valleys may mark normal faults, in which case, a repetition of the same part of the section would result. In the latter case a likely minimum thickness of the Carswell Formation would be about 320 m, the greatest thickness exposed within one dolomite ridge. If the valleys are due to the other reasons described above, a minimum thickness of about 625 m is likely.

In the Points Lake traverse, the last 825 m (horizontally) across the Carswell Formation were not studied. If the uniform dips of the first 625 m extend to this part of the traverse, then a total thickness of the Carswell Formation exposed in this section is about 1060 m, barring repetition of parts of the section. Extending this dip is not unreasonable as, countrary to Fahrig (1961), the inside of the carbonate ring is also relatively undisturbed in many places, and may dip towards the center of the structure without overturning. The type section shows this clearly. These minimum estimates of the thickness of the Carswell Formation are much greater than those of Currie (1969) who suggested a minimum thickness of 189 m for the entire unit.

The estimate of 1060 m, would suggest an unproven depth to basement of about 1800 m below the dolomite ring, assuming a constant dip of about 45° and a relatively unaltered sandstone thickness, both reasonable, but somewhat tenuous assumptions. This thickness for the carbonates compares favourably with similar sequences, such as those of the Hornby Bay (450 m) and the overlying Dismal Lakes Group (about 1050 m) in the Great Bear Lake region of the Northwest Territories.

In summary, a minimum thickness of 625 m for the preserved parts of the Carswell Lake Formation is highly likely, but a minimum thickness as great as 1060 m cannot be ruled out at present.

Lithology:

The Carswell Formation consists largely of dolomite. A basal section up to 60 m thick contains sandstones, mudstones and some dolomitic mudstones. Detrital quartz grains are present throughout the dolomites. The carbonates are largely algal laminates; the laminae are generally thin (1 mm) and are quite pronounced on weathered surfaces, but may be invisible on fresh surfaces. They ultimately weather into thin slabs and pebbles.

Stromatolitic units are common through much of the Carswell Formation and generally consist of LLH (laterally linked hemispheroids) forms extending at times over

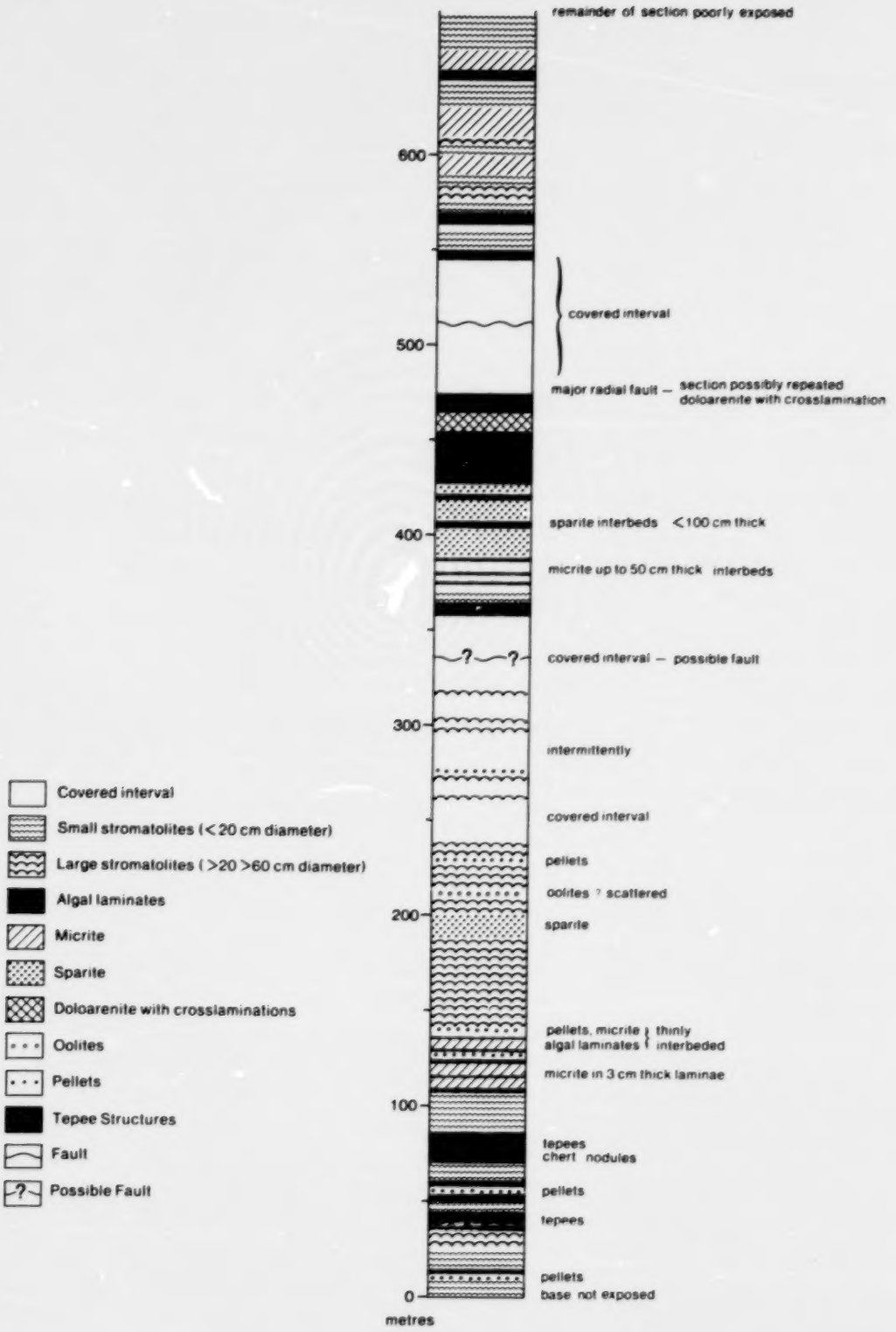

Figure 23 - Section through the Carswell Formation northwest of Points Lake.

large areas; exposures of 300 m by 50 m of a single stromatolite covered surface are known. Domes are typically circular in plan; elongated domes were not noted. Stromatolitic domes vary in size from several centimetres to 60 cm in diameter, and form layers from a few centimetres thick to stacks of 60 cm. Stacked, concave, polygonal stromatolites are common, which probably gave rise to many erroneous reports of overturned beds in the Carswell Formation.

Dolarenites are less common and locally show cross-bedding and ripple marks; no marked concentration at any particular stratigraphic level was noted.

Oolites up to 3 mm in diameter occur either as closely packed, well-sorted beds up to 15 cm thick, or in a dololutite matrix-supported wackestone with reworked algal laminate, dololutite or oolite intraclasts. Oolite structure varies from thin concentric layers to mostly radially oriented crystals. They are almost always spherical. Scattered oolites and pellets can be found in hollows between stromatolitic domes.

Beds of tectonically undisturbed, brecciated algal laminates and other brecciated dolomites are common. They occur in units up to 1 m thick lying conformably between undisturbed beds and as channel fills crosscutting other units; near vertical sides and depths of more than 1.2 m are characteristic.

Tectonic breccias are also common, in particular near the well exposed radial faults. They typically have calcite and quartz-filled fractures and are stained red by hematite.

Stylolites and tepee structures are common. Closely spaced symmetrical tepee structures may also have contributed to erroneous reports of overturned dolomite beds.

Thin 1-10 mm laminae of chert and beds of lenticular chert nodules are present along bedding planes, and seem more common in the algal laminates. Diagenetic quartz between and within oolites is common and may form up to 2 percent of oolites and dolarenites.

Intrusives

Definition, Distribution and Dimensions:

Gabbroic dykes, diabasic to subophitic in texture, are found throughout the Athabasca Basin (Figure 4). They are typically grey to dark green and fine to coarse grained, with the largest crystals up to 5 cm long.

The dykes occupy northwest-trending fracture or fault zones throughout the Athabasca Basin. In the southern Mirror Sub-basin they reoccupy north to north-northwest-trending Hudsonian fault zones and associated younger extensions into the Athabasca Group. A number of dykes do not lie on any known structural lineaments. Along the east-central margin of the Athabasca Basin exists a complex set of intrusions with a poorly defined northeast trend: the Moore Lakes complex.

Many dykes produce prominent magnetic lineaments, forming positive anomalies, but a few dykes within the Cree Lake Swarm have negative associated magnetic anomalies, and still others show no magnetic expression. Fortuitous intersections of dykes in boreholes indicate that dykes are more common than present maps indicate.

Attitudes of individual dykes within a swarm vary greatly as to strike and dip. The contact zones are nearly always poorly exposed, but the dips vary from 20° to 90° among closely spaced dykes. They are extensively jointed and sporadically faulted.

The dykes range from a few hundred to several thousand metres long and from about 1 to several hundred metres thick. Their topographic expression ranges from negative in many instances to ridges up to 20 m high. In some areas, particularly around the Cree Lake dykes and the Moore Lakes Complex, dykes and altered sandstones form prominent hills rising to 100 m above the surrounding area.

Lithology:

The dykes are typically gabbroic in composition and largely composed of elongated plagioclase (usually labradorite) and augite laths (Ramaekers and Hartling, 1979). Up to 15 percent magnetite may be present, resulting in strongly magnetic rock. No obvious difference in magnetite content was noted between dykes with positive, negative or no magnetic anomalies. Olivine, pigeonite, hornblende, orthoclase, apatite, quartz, biotite and chlorite are present in minor amounts. Rapid cooling of the dykes is indicated by the elongated nature of most crystals and the presence of pigenonite and granophyric intergrowths.

The Athabasca sandstones are altered up to 50 m from the dykes; silicification by quartz overgrowths and the destruction of colour banding have resulted in a uniform, dark grey or pinkish grey rock. Close to the dyke the sandstones may be brecciated, sedimentary structures may be obliterated, and a vuggy porosity is produced. Columnar jointing is evident in the sandstones adjacent to the dyke. Columns are perpendicular to the contact surface and increase in size (but decrease in definition) away from the dyke. They can appear spectacularly well-developed within 5 m of the contact. Malachite can be found in the altered sandstone.

Xenoliths of sandstone are few, ranging from several centimetres to about 10 m. They may be intensely silicified.

Fractures in the dykes are typically stained red by hematite and some are bordered by reddish hematitic alteration zones up to 10 cm thick. Some fractures are lined with euhedral quartz and calcite, and are stained by malachite in places. In boreholes the dykes are altered to a mixture of pale green clays and silica. The degree of alteration varies from zones several feet thick along the contact of the dyke to complete replacement of the intrusive by clays.

Phanerozoic Cover

An erosional hiatus separates the Athabasca Group and its contained intrusives from overlying flat-lying remnants of Devonian carbonates and Cretaceous clastics. All of these directly overlie the Athabasca Group in the southwestern part of the Athabasca Basin. Up to 200 m thick Pleistocene tills and periglacial deposits cover the bedrock of the basin.

Devonian Deposits

Glacial erratics of Devonian, fossiliferous carbonate are present along the southwestern border of the Athabasca Basin in NTS area 74F. These are probably derived from the Methy Dolomite, and indicate the presence of as yet undiscovered outliers of this unit (Figure 24).

Cretaceous Deposits

Deep valleys excavated in friable material in the southwestern part of the Athabasca Basin (NTS 74F) are similar morphologically to those excavated in the Mannville Group further south and west. These suggest a distribution of Cretaceous deposits as illustrated in Figure 24.

Coaly debris similar in appearance to reworked Cretaceous coals (common in parts of British Columbia and in the Eureka Sound Formation of the Northwest Territories) are found along the southwestern shore of Patterson Lake, and suggest the presence of coal bearing Mannville Group sediments in the vicinity.

Boreholes drilled by Canadian Occidental Petroleum have also encountered friable, silty fine sandstones with interbedded siltstones and mudstones, directly overlying the Athabasca Group. These contain six genera of foraminifera, among them abundant *Miliammina manitobensis*. This fauna, identified by W.G.E. Caldwell (pers. comm.), is characteristic of faunal zone III of North and Caldwell's (1975) Cretaceous Saskatchewan Foraminifera sequence, and indicates a stratigraphic level just below the Fish Scale Marker of the Lower Colorado Group. The soft friable Cretaceous clastics are probably more common than drill logs indicate, as non-coring tricone bits are generally used in drilling until the more resistant, indurated sandstones of the Athabasca Group are reached.

Pleistocene Deposits

Glacial and periglacial deposits form an extensive cover up to 200 m thick over the bedrock. Thickness varies erratically, especially over fault zones. Areas underlain by the Wolverine Point Formation, the Douglas Formation and the conglomeratic member of the Manitou Falls Formation typically have thick glacial cover.

The lower levels of the Pleistocene cover are generally composed of compacted, sandy, boulder-rich basal till. Variations in clast imbrication and drumlin axis direction, and multiple directions of glacial striae indicate the presence of several till sheets, in places superimposed. The directions of drumlin axes and glacial striae on bedrock show that the ice sheets entered the Athabasca Basin from the northeast and fanned out, moving west along the northern margin and east-southeast along the eastern margin.

Structureless ablational till forms a thin veneer over large areas of the basal till and esker deposits. Eskers and glaciofluviatile deposits are extensive in the Athabasca Basin and generally overlie the tills. Eskers frequently overlie fault zones in the Athabasca Basin.

Esker and outwash sands were the main source of sediment for the locally extensive glaciolacustrine deposits. These are best developed along the south shore of Lake Athabasca and in the Fond-du-Lac and Cree River Valleys. They consist of multiple raised, cobbly to sandy beaches and thick well-sorted sands interbedded with minor clays. Smaller lakes throughout the Athabasca Basin commonly show raised beaches and sandy or thin clay deposits marking former higher water levels. Glaciofluviatile and glaciolacustrine deposits form the main supply for the periglacial and modern eolian deposits that form a discontinuous, thin, but areally extensive veneer over much of the Athabasca Basin.

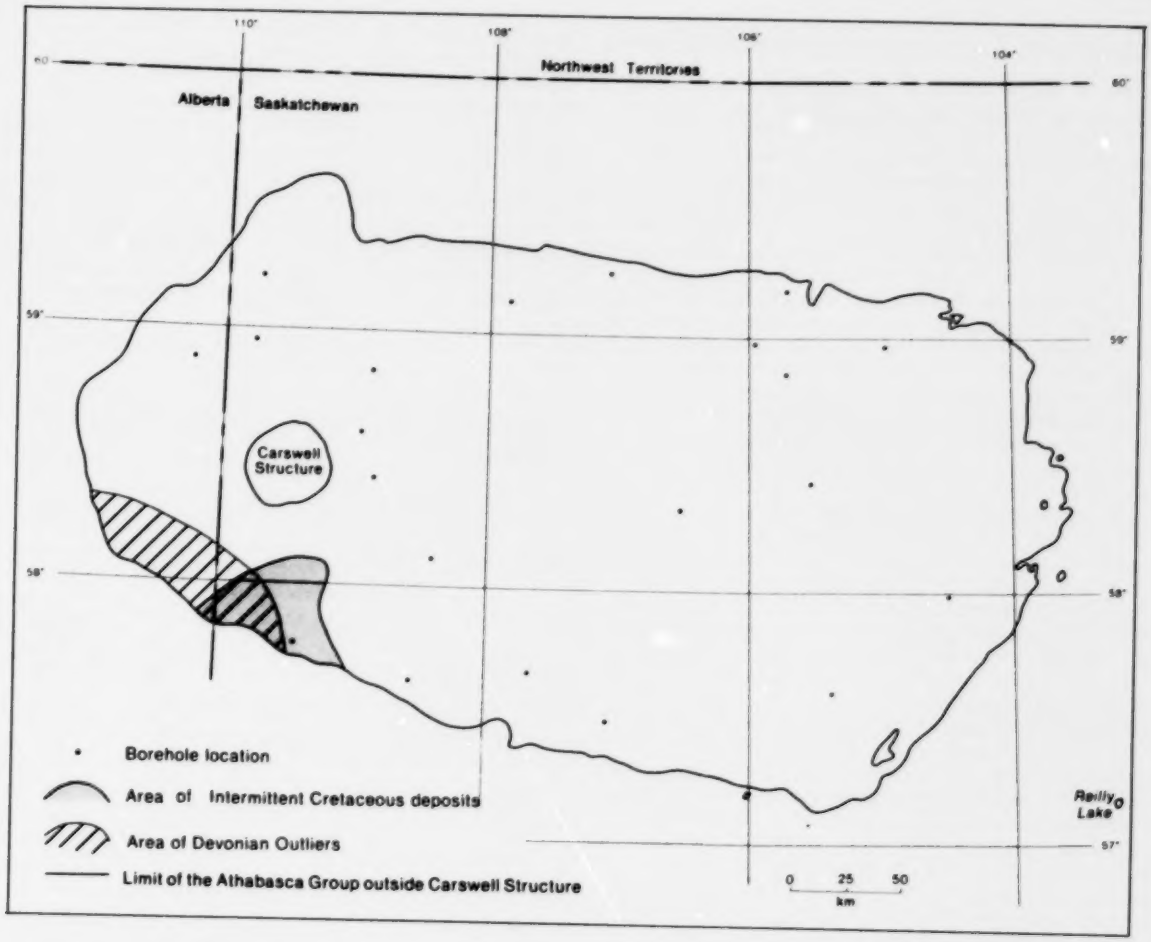

Figure 24 - Estimated limits of Devonian outliers and Cretaceous deposits over the Athabasca Group.

Structural Geology of the Athabasca Basin

Structural Domains of the Athabasca Basin

Patterns of magnetic intensity shown on aeromagnetic maps of northern Saskatchewan (Agarwal, 1962; 1965a; 1965b) indicate that basement rock around the Athabasca Basin is divisible into several distinct domains (Lewry and Sibbald, 1977) which are traceable beneath the sandstone covered areas. Within the Athabasca Basin, the domain boundaries tend to coincide with formational boundaries at the present surface indicating that movement related to these major basement units played a part both in the formation of the Athabasca Basin and in its subsequent deformation. Thus, an analysis of Athabasca Group stratigraphy provides a means by which to date Paleohelikian movement of some of the major basement fault zones of northern Saskatchewan.

The regional background pattern on the magnetic intensity maps is formed by broad northeast-trending (045°) trending bands that correspond to major crustal domains and reflect Hudsonian events (Lewry and Sibblad, 1977). Only the area between the 060° striking Black Bay and the Grease River Faults (Figure 3) diverges markedly from this regional strike. The domains may be distinguished from each other by their distinctive patterns of magnetic intensity, which correspond in some measure to their component lithologic units.

The boundaries of the basement domains also coincide with the structural subdivisions of the Athabasca Basin (Figure 1). The Jackfish Sub-basin is confined to the area west of the Firebag Domain and west of the Black Bay and allied faults. The Patterson High coincides with the Firebag and Clearwater Domains in the south and the Grease River Belt in the north. The Mirror Sub-basin overlies the Western Granulite and Virgin River Domains and straddles the Virgin River - Black Lake Shear Zone. This shear zone developed into a structural high, the Dufferin High, with the Cree Sub-basin to the east overlying the Virgin River, Mudjatic and Wollaston Domains (the Cree Mobile Zone of Lewry and Sibbald, 1977). The boundaries between the basement domains are generally major zones of brittle post-Athabasca faulting along older mylonite belts, suggesting that much of the tectonism involved in the origin of the Athabasca Basin was due to reactivation of Hudsonian structures.

Magnetic Lineaments Delineating Faults

Superimposed on the broad magnetic patterns marking the basement domains are sets of parallel or subparallel lineaments which distinguish two areas of the Athabasca Basin from the rest. The most widespread set of these lineaments trend roughly north (about 350°) and are closely spaced. They are prominent along the northern side of the Athabasca Basin (east of the Virgin River - Black Lake Shear Zone), and to the east and southeast. The lineaments coincide with similar patterns of left-lateral, normal faults (Johnston, 1963, 1964; Gilboy, 1978; Ray, 1978; Wallis, 1970c; Forsythe, 1980; Ray, 1977).

The other prominent lineament pattern occurs in the south-central area of the Athabasca Basin and trends northwest at about 330°. There are fewer lineaments per unit area, but they are more continuous and not as closely spaced as the first set described. They are confined to the Mirror Sub-basin area and straddle the Virgin River - Black Lake Shear Zone. These lineaments also correspond to faults (Scott, 1978) which, although their average strike is slightly different, bear the same angular relation to the Virgin River - Black Lake Shear Zone (here trending more northerly) as do the north-trending faults of the Black Lake region.

Evidence of Faults Within the Athabasca Sandstones

Faults in the Athabasca sandstones are almost never exposed. In core, major faults are often seen to consist of a thin (1 to 50 cm) layer of gouge or structureless sandstone surrounded by a brecciated zone from 0 to 20 m wide. Generally the brecciation is moderate and leaves the rock in its original attitude, but with numerous thin joints 1 to 5 mm wide. These may be open or lined with euhedral quartz, less commonly with siderite, or rarely with calcite, apatites, dickite, nacrite, chlorite, pyrite or copper, lead, zinc and uranium minerals. The sandstone along the fractures is typically leached of hematite, but may be indurated by iron oxides such as specular hematite, earthy hematite or limonite. More than one episode of silicification may be evident.

More rarely, the fault breccia is severely disrupted and a wide zone (up to 5 m) of sandstone rubble and vein quartz is present. A few major faults show sandstone dragged along the fault plane and displaced up to 60° from horizontal; in others, such as at Fir Island in Black Lake, chaotic displacement of the bedding is evident to the extent that conical structures (tight folding or possibly shatter cones) are present.

At the surface even major faults, marked by prominent scarps and with a known apparent displacement of several hundred metres, generally provide little evidence of actual displacement, e.g. the Black Lake Fault. Small fractures with displacement of 1 to 10 mm, greatly varying strikes, and possibly with some poorly preserved slickensides may be found in the outcrops of the scarp. The main structures themselves are almost always buried in topographic lows under muskeg, lakes or glacial debris, but they are commonly marked by eskers and river valleys.

Near the edges of the Athabasca Basin, topographic lineaments can often be traced to faults or fracture zones in the adjoining basement outcrops. This is very clear in the Stony Rapids mapsheet (NTS 74P, Gilboy and Ramaekers, 1981). In the Athabasca Basin, some outcrops are found along topographic lineaments that show prominent fractures parallel to the lineaments. Anomalously high mineral concentrations in tills, bedrock, and lake sediments are found along such

zones. Hence, it may reasonably be assumed that in the Athabasca Basin most topographic lineaments are expressions of buried fault or fracture zones, particularly if the lineaments are not parallel to the local direction of glacial advance.

Jackfish Sub-basin

The major faults affecting the development of the Jackfish Sub-basin are: the Black Bay Fault; northeast- and east-trending faults such as the St. Louis Fault and faults in the Maurice Bay area; the westerly extensions of the Grease River Fault Zone; and northwest-trending faults such as those through Fidler Point.

The Jackfish Sub-basin and the Fair Point Formation are confined largely to areas west of the Black Bay Fault. The coarse quartzite cobbles, altered dark mafic pebbles, and immature depositional composition of the Fair Point Formation strongly suggest local derivation, probably from Tazin Group, Thluicho Lake Group, and Martin Formation type redbed units. The absence of significant amounts of coarse clastics to the east at this stratigraphic level suggests the presence of major scarps along the trace of the Black Bay Fault with a downthrown western side - similar to the situation in Black Bay. Sections through the Jackfish Sub-basin (Figure 6, Section 1) suggest that the Fair Point Formation thickens to the north, and implies that the centre of subsidence at this time lay at the northern edge or to the north of the present Athabasca Basin.

After Fair Point time, rather scanty evidence (Figure 6, Section 1) suggests that the Manitou Falls Formation of the Jackfish Sub-basin thickens to the southwest on a line extending from Fidler Point to Cluff Lake. This line is also marked by faulting parallel to it at Fidler Point (with the southwestern side downthrown) and a deflection of the Tuma Lake Formation boundary. Taken together, this evidence suggests that the fault zone, here named the Fidler Fault Zone, marked the northeastern edge of a northwest-trending graben. The structure was most active at Manitou Falls time, but also sporadically thereafter; enough, at least, to affect the Tuma Lake Formation outcrop pattern, and to fracture the dolomites of the Carswell Formation. These dolomites, where intersected by the fault, were greatly excavated by Pleistocene glaciers. Further to the southeast, marked changes in outcrop pattern of the Carswell and Douglas Formations occur in the Cluff Lake area (Figure 23) and in the Locker Lake/Otherside Formation boundaries where intersected by the Fidler Fault Zone.

Thickening of the Wolverine Point (a) member shows that the Jackfish Sub-basin was still subsiding at that time relative to the rest of the Athabasca Basin. The partial removal or reduced development of the Wolverine Point Formation in the southwest part of the Athabasca Basin (Chevron 77-4 borehole, available for inspection at the Alberta Research Council in Edmonton) indicates the presence of a local structural high. The little evidence available suggests that later subsidence in the Jackfish Sub-basin seems to have been similar to that elsewhere in the Athabasca Basin.

The Patterson High

The Patterson High is developed in the Athabasca Basin from east of the Black Bay Fault to the western edge of the Western Granulite Domain. It overlies their Firebag and Clearwater Domains and thus, incorporates the Grease River Fault Zone, which forms the northern end of the Clearwater Domain.

A series of horsts trending 035° are indicated by positive magnetic anomalies coinciding with anomalous maximum grain sizes of the sediments. They form the major structural feature of the Patterson High and parallel the magnetic pattern which forms the basis for delineating the Clearwater Domain. Horsts also occur off the main trend. For example, the strong magnetic anomaly south of Tuma Lake marks a horst which brings the Wolverine Point (b) member to the surface: a vertical displacement of about 300 m. Northwest trending dykes seem to be offset where they cross the line of horsts of the Clearwater Domain, suggesting the possibility that these structural features postdate dyke intrusion.

Lineaments consisting of rows of lakes parallel to the trend of the horsts are present in the area (e.g. due north of the Carswell Structure or the north arm of Snare Lake), but they are not very common.

The most common major parallel topographic lineaments of the Patterson High are lines of lakes trending 050° to 060°, sub-parallel to the Grease River Fault trend. They are made obvious by glacial excavation as they are roughly parallel to the glacial trend over most of the area. A very prominent fracture trend parallel to this direction is present throughout the northern part of this area where it is well exposed in the east-west escarpment formed by outcrops of the Locker Lake Formation between Riou and Richards Lakes.

The symmetry of minor faults, possibly a conjugate set, around the Grease River Fault where it is well exposed north of the Athabasca Basin (Johnston, 1960, 1961) suggests reverse movement with dips to the northwest. Colborne and Rosenberger (1963) indicate both reverse and right-lateral movement on the Grease River Fault. Reverse movement about this fault trend in the Athabasca Basin would explain the steep basin slope gradient along the north-central edge of the Athabasca Basin, as well as the reason for the Patterson High being adjacent to the Mirror Sub-basin.

Mirror Sub-basin and the Dufferin High

Basement below the Mirror Sub-basin comprises the western Granulite Domain, the Virgin River - Black Lake Shear Zone and probably part of the Virgin River Domain. The Western Granulite Domain is characterized by northwest-trending (about 330°) left-lateral faults which contain Late Hudsonian metamorphosed dykes (Scott, 1977) in basement areas and unmetamorphosed Neohelikian dykes in the Athabasca sandstones. Faults of this trend, also intruded by Neohelikian dykes, are also present in the Virgin River Domain immediately to the east of the shear zone.

Two fault trends are prominent along the Black Lake Fault in the basement area to the north of the Athabasca Basin: north-trending left-lateral normal faults which coincide with the prominent lineaments on magnetic intensity maps; and east-trending right-lateral reverse faults (Johnston, 1963, 1964).

If these trends are related they would form a conjugate set about the Black Lake Fault and indicate left-lateral movement on the latter. The northwest-trending dykes of the Athabasca Basin bisect the angle of intersection of this conjugate set. This is the direction of maximum tensile stress in such a left-lateral shear system and suggests that either the dykes occupied fracture zones formed at the time of left-lateral movement along the Black Lake Fault or the intrusions accompanied the faulting.

The same fault pattern is also found in the Athabasca sandstones along the Virgin River - Black Lake Shear Zone and mark the formation bounderies between the Locker Lake and Otherside Formations.

The Mirror Sub-basin contained the Manitou Falls (a) member during its initial development and indicates subsidence over the Western Granulite and Virgin River Domains and the Virgin River - Black Lake Shear Zone relative to the rest of the Athabasca Basin at that time. During Manitou Falls (b) and (c) time, the Mirror Subbasin probably subsided at roughly the same rate as the rest of the area. During Manitou Falls (d) time, the locus of greatest subsidence shifted to the east where it formed the Cree Sub-basin, overlapped the Mirror Subbasin east of the Virgin River - Black Lake Shear Zone which was a relative high: the Dufferin High.

In Lazenby Lake time the Mirror and Jackfish Subbasins received increased sediments from the south. Whether the rate of subsidence increased relative to other parts of the Athabasca Basin has not been determined due to facies changes northwards and eastwards and lack of preservation of these strata in the Cree Subbasin area.

Relative thickening of the Wolverine Point (b) member in the Mirror Sub-basin may indicate increased subsidence here at this time. However, the paucity of data and the difficulty of defining a time equivalent level within the Wolverine Point Formation leave open the possibility that the boundary between the Wolverine Point (a) and (b) members is diachronous and hence, that the change in thickness between the members does not reflect changes in the rate of subsidence.

Stratigraphically higher strata in the Mirror Sub-basin thicken somewhat to the south but not enough to indicate significant changes in rate of subsidence within this basin or changes relative to the Jackfish Sub-basin. Lack of preservation of the higher stratigraphic levels to the east preclude comparisons with the Cree Sub-basin, except to indicate the possibility that later uplift and erosion were greater there than in the western part of the Athabasca Basin.

The Cree Sub-basin and the Pasfield High

Similar in style to the Virgin River - Black Lake Shear Zone are the Cable Bay Shear Zone, the Keefe Lake Fault Zone, and major northeast-trending lineaments such as those along Holgar Lake (NTS 74G), Wheeler Lake (NTS 74H) and Unknown Lake and Waterfound Rivers (NTS 74I). Easterly striking right-lateral reverse faults of the Rabbit Lake and Key Lake type probably form a conjugate set with the north-trending left-lateral normal faults (Ray, 1977) around the major northeasterly faults. The northeasterly- and northerly-trending structures are marked by prominent lineaments formed by lakes, eskers and river valleys. The easterly trending faults show poor topographic expression.

Marked thickening of the Manitou Falls (d) member east of the Virgin River - Black Lake Shear Zone indicates subsidence of the area relative to the rest of the Athabasca Basin and defines the Cree Sub-basin and the relative high at its western margin, the Dufferin High. Thus, the Cree Sub-basin possibly marks a shift of the Mirror Sub-basin depocentre to the east, reflecting increased influx of sediments from that direction. Lack of preserved overlying beds leaves the subsequent history of the Cree Sub-basin unclear, but suggests a greater amount of post-Athabasca Group uplift relative to the western part of the Athabasca Basin.

The Pasfield High is poorly defined, largely on the basis of the distribution of maximum grain sizes at the present surface flanked by a prominent topographic lineament. Lack of reliable depth to basement information in the area leaves it unclear whether the high is a post-Athabasca horst or whether it reflects syndepositional tectonism.

Carswell Structure

The Carswell Structure is a roughly circular tectonic feature about 38 km in diameter located in the interior of the Athabasca Basin (NTS mapsheet 74K). Within the inner core of the structure (about 20 km in diameter) basement gneisses are exposed at the surface. The basal contact between Athabasca Group sandstones and the basement is overturned (Harper, 1978b).

Along the outside of the structure the Douglas and Carswell Formations dip inward at about 30° to 50°, but are not overturned. Douglas Formation subcrops within the ring of the Carswell Formation exposures as well. Evidently, a profound angular unconformity exists somewhere between the inner ring of overturned clastics of the Athabasca Group and the upper levels of the dolomites. Its exact stratigraphic level probably varies and has not been defined precisely thus far. A complex series of radial and concentric ring faults is found throughout the structure, superimposed on the major prominent northeast- and the less obvious northwest-trending faults characteristic of the western Athabasca Basin (Amok, 1974).

Summary of Structural History of the Athabasca Basin

The Athabasca Basin contains three depositional sub-basins due to syndepositional tectonism. The two easterly sub-basins overlap and are closely related. By the end of Manitou Falls time tectonism decreased and gradually the entire Athabasca Basin began acting as a single basin. Total preserved sediment thickness in the Athabasca Basin is at least 2300 m.

The styles of faulting varied within the Athabasca Basin: west of the Virgin River - Black Lake Shear Zone faulting was more complex and involved a greater amount of horst and graben formation, but much of this may postdate deposition of the Athabasca Group. The dominant structural features of the Athabasca Basin are probably rejuvenated northeast-trending Hudsonian wrench faults.

References

Agarwal, R.G. (1962): Regional correlation of geological and geophysical data in the Lake Athabasca area, northern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 75, 4p.

---------- (1965a): Regional correlation of geological and geophysical data in the Cree Lake area, northern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 94, 4p.

---------- (1965b): Regional correlation of geological and geophysical data in the Wollaston Lake area; Sask. Dep. Miner. Resour., Rep. 82, 4p.

Alcock, F.J. (1920): The Athabasca Series; Am. J. Sci. (4th ser.), v50, no295, p25-32.

---------- (1936a): Geology of Lake Athabasca region, Saskatchewan; Geol. Surv. Can., Mem. 196, 41p.

---------- (1936b): The gold deposits of Lake Athabasca; Trans. Can. Inst. Min. Metall., v39, p531-546.

AMOK (Canada) Limited, (1974): The Carswell Circular Structure and Cluff Lake uranium ore-bodies; *in* Parslow, G.R. (ed.), Fuels: A Geological Appraisal; Sask. Geol. Soc., Spec. Publ. 2, p47-61.

Bell, C.K. (1961): Milliken Lake, sheet 2, Saskatchewan; Geol. Surv. Can., Map 33-1961 (with descr. notes).

---------- (1962a): Milliken Lake, sheet 4, Saskatchewan; Geol. Surv. Can., Map 33-1961 (with descr. notes).

---------- (1962b): Milliken Lake, sheet 3, Saskatchewan; Geol. Surv. Can., Map 33-1961 (with descr. notes).

---------- (1963): Milliken Lake, sheet 4, Saskatchewan; Geol. Surv. Can., Map 11-1962 (with descr. notes).

Bell, K. and Blenkinsop, J. (1980): Saskatchewan Shield geochronology project; *in* Summary of Investigations 1980, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 80-4, p18.

Blake, D.A.W. (1956): Geological notes on the region south of Lake Athabasca and Black Lake, Saskatchewan and Alberta; Geol. Surv. Can., Pap. 55-33, 12p.

Christie, A.M. (1953): Goldfields - Martin Lake map-areas, Saskatchewan; Geol. Surv. Can., Mem. 269, 126p.

Colborne, G.L. and Rosenburger, E. (1963): The geology of the Wiley Lake area (west half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 79, 29p.

Crowell, J.C. (1974): Origin of late Cenozoic basins in southern California; *in* Dickinson, W.R. (ed.), Tectonics and Sedimentation; Society of Economic Paleontologists and Mineralogists, Spec. Publ. 22, p190-204.

Currie, K.L. (1969): Geological notes on the Carswell Circular Structure, Saskatchewan (74K); Geol. Surv. Can., Pap. 67-32, 60p.

Donaldson, J.A. (1968): Proterozoic sedimentary rocks of northern Saskatchewan (74N); *in* Report of Activities, Part A: May to October, 1967; Geol. Surv. Can., Pap. 68-1A, p131.

Evans, M.E. and Bingham, D.K. (1973): Paleomagnetism of the Precambrian Martin Formation, Saskatchewan; Can. J. Earth Sci., v10, p1485-1493.

Fahrig, W.F. (1961): The geology of the Athabasca Formation; Geol. Surv. Can., Bull. 68, 41p.

Fahrig, W.F., Christie, K.W., and Freda, G. (1978): The paleolatitude and paleomagnetic age of the Athabasca Formation, northern Saskatchewan - reply; *in* Current Research, Part C; Geol. Surv. Can., Pap. 79-1C, p119-120.

Forsythe, L.H. (1980): Geology of part of the Geikie River (east) area; Sask. Dep. Miner. Resour., Rep. 204, 12p.

Fraser, J.A. (1954): Crackingstone, Saskatchewan; Geol. Surv. Can., Pap. 54-8 (map with descr. notes), scale 1:63 360.

---------- (1960): Crackingstone, Saskatchewan; Geol. Surv. Can., Map 1095A (map with descr. notes), scale 1:63 360.

Fraser, J.A., Donaldson, J.A., Fahrig, W.F., and Tremblay, L.P. (1970): Helikian basins and geosynclines of the northwestern Canadian Shield; *in* Baer, A.J. (ed.), Symposium on Basins and Geosynclines of the Canadian Shield; Geol. Surv. Can., Pap. 70-40, p213-238.

Furnival, G.M. (1941): Porcupine River, northern Saskatchewan: Geol. Surv. Can. Map no. 658A (with descr. notes).

Gilboy, C.F. (1978): Reconnaissance geology, Stony Rapids area (part of NTS area 74P); *in* Summary of Investigations 1978, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 78-10, p35-42.

---------- (1980): Bedrock compilation geology: Cree Lake area (NTS 74G); 1:250 000 scale prelim. map *with* Summary of Investigations 1980, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 80-4.

Gilboy, C.F. and Ramaekers, P. (1981): Compilation bedrock geology: Stony Rapids area (NTS 74P); *in* Summary of Investigations 1981, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 81-4, p6-11.

Gravenor, C.P. (1959): Heavy minerals of the Athabasca Sandstone; J. Alberta Soc. Pet. Geol., v7, p1-6.

Gussow, W.C. (1957): Correlation and age of the Athabasca Formation; J. Alberta Soc. Pet. Geol., v5, p2-5.

——— (1959): Athabasca Formation of western Canada; Geol. Soc. Am. Bull., v70, p1-18.

Hale, W.E. (1954a): Black Bay map-area, Saskatchewan (preliminary report); Geol. Surv. Can., Pap. 53-15, 18p.

——— (1954b): Gulo Lake, Saskatchewan; Geol. Surv. Can., Pap. 54-6 (map with marginal notes).

——— (1955): Forcie Lake map-area, Saskatchewan; Geol. Surv. Can., Pap 55-4 (map with marginal notes).

Harper, C.T. (1978a): Uranium metallogenic studies: Maurice Bay; *in* Summary of Investigations 1978, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 78-10, p74-83.

——— (1978b): The geology of the Cluff Lake uranium deposits; CIM Bull., v71, no. 800, p68-78.

——— (1979): Uranium metallogenic studies: Maurice Bay area, geology and mineralization; *in* Summary of Investigations 1979, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 79-10, p96-106.

Hobson, G.D. and MacAuley, H.A. (1969): A seismic reconnaissance survey of the Athabasca Formation, Alberta and Saskatchewan; Geol. Surv. Can., Pap. 69-18, 23p.

Hoeve, J. (1977): Uranium metallogenic studies: II Rabbit Lake, mineralogy and geochemistry; *in* Summary of Investigations 1977, Sask. Geol. Surv.; Sask. Dep. Miner. Resour., p124-135.

Hoeve, J. and Sibbald, T.I.I. (1978): Mineralogy and geological setting of uncomformity-type uranium deposits in northern Saskatchewan; *in* Kimberley, M.M. (ed.), Short Course in Uranium Deposits: Their Mineralogy and Origin; Mineral. Assoc. Can., Handbook, v3, p457-474.

Hoeve, J. , Sibbald, T.I.I., Ramaekers, P. and Lewry, J.F. (1980): Athabasca Basin unconformity-type uranium deposits: a special class of sandstone-type deposits; *in* Ferguson, J. and Goleby, A.B. (eds.), Uranium in the Pine Creek Geosyncline; IAEA, Vienna, p575-594.

Johnston, F.J. (1960): The geology of the Tantato Lake area (Astrolabe Lake - East half), Saskatchewan; Sask. Dep. Miner. Resour. Rep. 44, 32p.

——— (1961): The geology of the Astrolabe lake area (west half) Saskatchewan; Sask. Dep. Miner. Resour. Rep. 59, 26p.

——— (1963): The Lytle Lake area (east half); *in* Cheesman, R.L. (ed.), Summary report of geological surveys conducted in the Precambrian area of Saskatchewan, 1963; Sask. Dep. Miner. Resour., p19-22.

——— (1964): The geology of the Lytle Lake area (east half) Saskatchewan; Sask. Dep. Miner. Resour. Rep. 90, 8p.

Langford, F.F. (1980): Successor basins in the Beaverlodge area; *in* Summary of Investigations 1980, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 80-4, p29.

Lewry, J.F., and Sibbald, T.I.I. (1977): Variation in lithology and tectonometamorphic relationships in the Precambrian basement of northern Saskatchewan; Can. J. Earth Sci., v14, p1453-1467.

Lewry, J.F., Sibbald, T.I.I., and Rees, C.J. (1978): Metamorphic patterns and their relation to tectonism and plutonism in the Churchill Province; *in* Fraser, J.A. and Heywood, W.W. (eds.), Metamorphism in the Canadian Shield; Geol. Surv. Can., Pap. 78-10, p139-153.

Logan, B.W., Rezak, R., Ginsburg, R.N. (1964): Classification and environmental significance of algal stromatolites; J. of Geol., v72, no1, p69-83.

Macdonald, R., and Broughton, P. (1980): Geological map of Saskatchewan, provisional edition; Sask. Miner. Resour., scale 1:1 000 000.

Macey, G.J. (1973): A sedimentological comparison of two Proterozoic redbed successions (the South Channel and Kazan Formations of Baker Lake, N.W.T. and the Martin Formation at Uranium City, Saskatchewan); unpubl. M.Sc. thesis, McGill Univ.

McConnell, R.G. (1893): Report on a portion of the District of Athabasca, comprising the country between Peace River and Athabasca River north of Lesser Slave Lake; Geol. Surv. Can., Annu. Rep. (New Ser.), v5, 1890-91, pt1, Rep. D, p1D-67D.

Mellinger, M. (1980): Uranium metallogenic studies: Maurice Bay deposit; *in* Summary of Investigations 1979; Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 79-10, p107-110.

North, B.R., and Caldwell, W.G.E. (1975): Foraminiferal faunas in the Cretaceous System of Saskatchewan; *in* Caldwell, W.G.E. (ed.), The Cretaceous System in the Western Interior of North America, Geol. Assoc. Canada, Spec. Pap. 13, p303-331.

Price, R.A. (1965): Flathead map area, British Columbia and Alberta; Geol. Surv. Can., Mem. 136, 221p.

Ramaekers, P. (1975): Athabasca Formation, southeast edge (74H): Part 1 - reconnaissance geological survey; *in* Summary of Investigations 1975, Sask. Geol. Surv.; Sask. Dep. Miner. Resour., p48-52.

——— (1976): Athabasca Formation, northeast edge (64L 74I 74P); 1:250 000 scale preliminary map *with* Summary of Investigations 1976, Sask. Geol. Surv.; Sask. Dep. Miner. Resour.

——— (1977): Athabasca Formation, south-central edge (74G area); 1:100 000 scale prelim. map *with* Summary of Investigations 1977, Sask. Geol. Surv.; Sask. Dep. Miner. Resour.

——— (1978a): Athabasca Formation, southwestern edge (74F 74K): Part 1 - reconnaissance geology; 1:250 000 scale preliminary map *with* Summary of Investigations 1978, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 78-10.

——— (1978b): Athabasca Formation, southwestern edge: Part I, reconnaissance geology (NTS areas 74F, 74K); *in* Summary of Investigations 1978, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 78-10, p124-128.

——— (1979a): Sections through the Athabasca Basin; 1:1 000 000 scale prelim. map *with* Summary of Investigations 1979, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 79-10.

——— (1979b): Stratigraphy of the Athabasca Basin; 1:1 000 000 scale prelim. map *with* Summary of Investigations 1979, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 79-10.

——— (1979c): Stratigraphy of the Athabasca Basin; *in* Summary of Investigations 1979, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 79-10, p154-160.

——— (1979d): Surface geology of the Athabasca Group, NEA-IAEA test area; *in* Summary of Investigations 1979, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 79-10, p161.

——— (1980a): Sections through the Athabasca Basin; 1:1 000 000 scale prelim. map *with* Summary of Investigations 1980, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 80-4.

——— (1980b): Stratigraphy and maximum grain size distribution, Athabasca Basin; 1:1 000 000 scale prelim. map *with* Summary of Investigations 1980, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 80-4.

Ramaekers, P. and Dunn, C.E. (1977): Geology and geochemistry of the eastern margin of the Athabasca Basin; *in* Dunn, C.E. (ed.), Uranium in Saskatchewan; Sask. Geol. Soc., Spec. Publ. 3, p297-322.

Ramaekers, P. and Hartling, A.A. (1979): Structural geology and intrusive events of the Athabasca Basin and their bearing on uranium mineralization; *in* Parslow, G.R.(ed.), Uranium Exploration Techniques; Sask. Geol. Soc., Spec. Publ. 4, p221-234.

Ray, G.E. (1977): Compilation geology, Foster Lake area (74A); *in* Summary of Investigations 1977, Sask. Geol. Surv.; Sask. Dep. Miner. Resour., p43-50.

——— (1978): Reconnaissance geology: Wollaston Lake (west) area (part of NTS area 64L); *in* Summary of Investigations 1978, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 78-10, p25-34.

Scott, B.P. (1977): Reconnaissance geology: Upper Clearwater River area (part of NTS area 74F); *in* Summary of Investigations 1977, by the Sask. Geol. Surv.; Sask. Dep. Miner. Resour., p13-16.

——— (1978): Geological mapping, Laird Lake west area (63M-14W); *in* Summary of Investigations 1978, Sask. Geol. Surv.; Sask. Dep. Miner. Resour., Misc. Rep. 78-10, p13-15.

——— (1978c): Geology of an area east of Thluicho Lake, Saskatchewan; Sask. Miner. Resour., Rep. 167, 51p.

Sibbald, T.I.I. and Lewry, J.F. (1980): Uranium metallogenic studies: Lodge Bay area (part of NTS 74N-7); 1:31 680 scale prelim. map *with* Summary of Investigations 1980, Sask. Geol. Surv.; Sask. Miner. Resour., Misc. Rep. 80-4.

Sproule, J.C. (1938): Cree Lake area, Saskatchewan; Geol. Surv. Can., Pap. 38-9, 13p.

——— (1941): Weitzel Lake, northern Saskatchewan; Geol. Surv. Can., Map 576A (with marginal notes), Scale 1:253 440.

Sproule, J.C. and Downie, D.L. (1941): Brustad River, northern Saskatchewan; Geol. Surv. Can., Map 577A (with marginal notes), scale 1:253 440.

Sproule, J.C., Ellis, S.C., and Downie, D.L. (1941): Upper Clearwater River, northern Saskatchewan; Geol. Surv. Can., Map 578A (with marginal notes), scale 1:253 440.

Steel, R.J. (1976): Devonian basins of western Norway - Sedimentary response to tectonism and to varying tectonic context; Tectophonics, V. 36, p. 207-224.

Tremblay, L.P. (1972): Geology of the Beaverlodge mining area, Saskatchewan; Geol. Surv. Can., Mem. 367, 265p.

Tyrrell, J.B. and Dowling, D.B. (1896): Report on the country between Athabasca Lake and Churchill River; Geol. Surv. Can., Annu. Rep. (New Ser.), v8, 1895, ptD, p1D-120D.

Wallis, R.H. (1970c): The geology of the Dufferin Lake area (west half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 132, 59p.

Winkler, H.G.F. (1967): Petrogenesis of Metamorphic Rocks; Revised second edition, Springer-Verlag New York Inc.; 237p.

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